

Industrial Temperature Capacitive and Inductive Transducers by an Hg Thermometer.

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Abstract - The extension of high-power applications in industrial processing is very much dependent on the development of efficient and powerful transducers. Obviously, when dealing with industrial applications. One tries to implement the capacitance and inductive transducers' field to temperature measurements, at present, losing. The illustrated temperature capacitive and inductive transducers by an HG thermometer cover this losing. Moreover these transducers respond to the necessity, in the industrial environment, for combining accuracy with the simplicity and product durable life. Which makes for reliability. The illustrated transducers use the column of HG of mercurial thermometer either as the movable armature of a capacitor or as the secondary movable coil of a mutual inductor. Experimental illustrated transducers have been developed and test results prove their compliance with the outlined requirements.

I. Introduction

Capacitance transducers [1] cover many fields of applications: humidity sensors [2], Gas flow sensors [3]. Pressure sensors [4], etc. Also inductive transducers are widely used. E.G. the magnetoelastic transducers [5] are suitable to be used for measuring force, moment and pressure, respectively, primarily under extremely heavy environmental conditions (high operating temperature, aggressive chemical pollution, intensive electromagnetic interference, vibration). The primary concern of heating services [6] today is to accurately measure and charge the heat consumption. The continuous control of the whole or a part of the heating system is also important from the point of view of the safe and the profitable system management. The primary task of a heat meter is to calculate the heat consumption from the heating warm water and temperature of the forward going and the returning water. That involves a differential transducer of temperature. At Kennedy Space Center [7] transducer used are designed and tested to meet specific program requirements. Examples of testing designed to verify requirements related to transducers safe operation are normally the following: - Vibration testing. - EMI/EMC testing based on MIL-STD-461. Testing is also performed to assure accurate, predictable, repeatable measurements are provided to support critical operations. As example, the following testing and analytical calculations are performed: - Linearity, repeatability, hysteresis, accuracy and error band calculations to assure measurement. - The extension of high-power applications in industrial processing are very much dependent on the development of efficient and powerful transducers. Obviously, when dealing with industrial applications. One tries to implement the capacitance and inductive transducers' field to temperature measurements, at present, losing. Moreover these transducers respond to the necessity, in the industrial environment, for combining accuracy with the simplicity and product durable life. Which makes for reliability. - Demand for cost and high performance packages is increasing in the recent years. Multi- chip packaging is one of the key enabling technologies in realizing high performance packages. Package level thermal design is one of the challenging tasks in the development of high power multi- chip packages. -Thermal design optimization of package heat spreader and a relative performance of thermal Interface Materials (TIM) [8] in the multi- chip package, thermal simulation methodologies and measurement methodologies are at present required. - Thermally activated processes like interdiffusion and recrystallization can degrade quality of chip-to-lead interconnections and solder joints. Mismatch of thermal expansion coefficients in combination with cycling operation temperature cause enormous strains that can essentially accelerate fatigue processes and reduce

the circuit reliability. For investigating the thermal behavior of semiconductor components. Both, steady-state and dynamic investigations have to be performed and the simulation results compared with results established in experimental procedures.

A mercurial thermometer bases the illustrated transducers denoted “industrial transducers of temperature by a mercurial thermometer”. The illustrated transducers use the column of HG of mercurial thermometer either as the movable armature of a capacitor or as the secondary movable coil of a mutual inductor. Experimental illustrated transducers have been developed and test results prove their compliance with the outlined requirements.

II. Basic Principle of the Temperature Transducers by an HG Thermometer

The conversion temperature-volume expansion of HG by a mercurial thermometer bases the principle of the illustrated transducers. The column of HG of the mercurial thermometer is used as the movable either armature or secondary coil respectively of the temperature -capacitance transducer and temperature -self-inductance transducer. The characteristic of the transducers are linked with the one between temperature and the level, l , of the column of HG in the glass capillary of mercurial thermometer. The illustrated transducers intrinsically respond to EMI/EMC testing based on MIL-STD-461. This testing assures transducers and equipment does not emit or are susceptible to electromagnetic and radio frequency interference that could affect their nominal operation. Moreover industrial transducers of temperature by a mercurial thermometer appear to responding to the necessity, in the industrial environment, for combining accuracy with the simplicity and product durable life. Which makes for reliability. Industrial transducers of temperature by a mercurial thermometer implement the capacitance and inductive transducers’ field to the measurements of temperature, at present, losing.

A. The Temperature-Capacitance Transducer

A metal film (the fixed electrode of the capacitive transducer). coats the outer glass surface of the mercurial thermometer. The movable electrode is the column of HG. The glass capillary of mercurial thermometer at the top end is opened. A very thin wire, through this hall, at one terminal is immersed in the column of HG to the lower of the range of temperature of the transducer and the second terminal is the one of the movable electrode of the transducer. It may be useful to allowing the view of the scale of mercurial thermometer by a thin window in the fixed metal film electrode. With d and D the inner and outer diameter of the glass capillary and ϵ_r the dielectric constant of glass. The capacitance (C) per millimeter of the capillary length from,

$$C = \frac{2\pi\epsilon_0\epsilon_r l}{\ln \frac{D}{d}} \left[\frac{pF}{m} \right], \text{ is, } C \cong \frac{0.05563 \epsilon_r}{\ln \frac{D}{d}} \left[\frac{pF}{mm} \right].$$

With the current values, $\epsilon_r \cong 6.8$, $\frac{D}{d}=1.4$ is, $C \cong 1.12$ pF/mm. The range of temperature of the temperature - capacitance transducer and its overload may be assigned during its design.

As outlined, see Section 1, to measure and charge the heat consumption the task of a heat meter is to calculate the heat consumption from the heating warm water and temperature of the forward going and the returning water. These industrial applications involve the conversion differential capacitance (ΔC), with $\Delta C = C_x + C_c$, to the output voltage V_o . The conversion $\Delta C - V_o$ may be performed by both a ratio transformer bridge used as deviation bridge, see Fig. 1, and, see Section 4, by a two wires double ac currents transmitter, with as inputs the two ac currents through C_x and C_c , and as outputs two dc currents proportional to the two ac inputs. By these conversions the power is driven by the sources and is not dependent from the output impedances. Moreover with shielded networks are imperious to noises.

B. The Temperature-Inductance Transducer

A coil, by a thin wire, is wound on the outer surface of the glass capillary surface of the mercurial thermometer. It may be useful to allowing the viewing of the scale of mercurial thermometer that wires should not be wound serrated. The variations of the self-inductance of the coil is not only due to the one of the relative permeability, μ_r of HG ($\mu_r \cong 1 + 10^4$) but to the variation of the column of HG that performs the role of the secondary of a mutual inductor with as primary the coil. The column of HG is equivalent to a current’s sheet wound on a circular tube with current density nearly proportional to the radius only (see Rosa Grover 1916). The mutual inductance of this current’s sheet with the fixed coil is a function of the level of the column of HG. And, than, the self-inductance of the coil varies with temperature. The characteristic (self-inductance - temperature) is not easily predictable. The characteristic self-inductance - temperature of our experimental transducer, see the Section 4, is exponential.

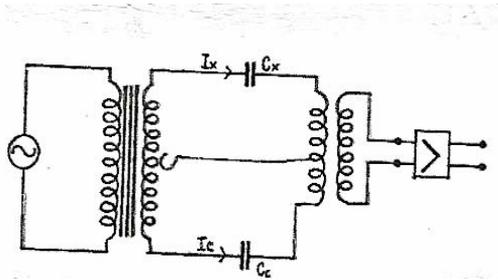


Fig. 1. Ratio Transformer Bridge used as deviation bridge for the conversion capacitance variation to voltage.

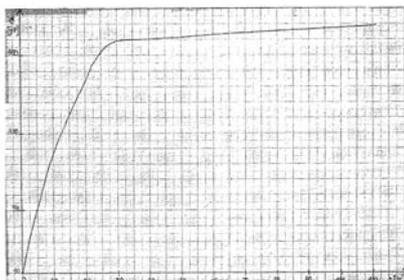


Fig. 2. Characteristic of capacitance to temperature

Tab 1. Characteristics of C to T. (A) In the range of T 0-20 °C. (B) In the range of T 40-120 °C.

(A)

T [°C]	0.5	15	20
C [pF]	51.9	113.4	134.7
Linearity [%]	0.02	0.03	0.02

(B)

T [°C]	40	75	110
C [pF]	160.1	164.7	169.1
Linearity [%]	0.02	0.04	0.02

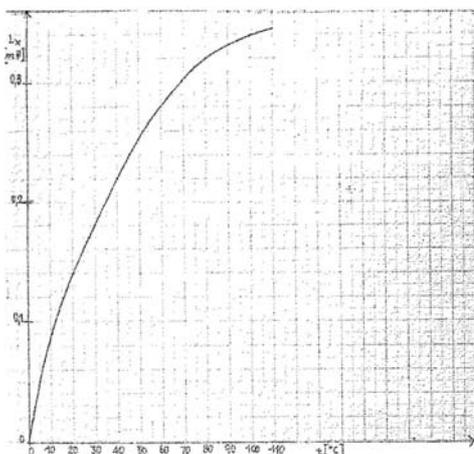


Fig. 3. Characteristic of inductance to temperature.

Tab. 2 Characteristics of L to T (A) in the range of T 20-70 °C. (B) in the range of T, 70-120 °C,

(A)

T [°C]	20	40	70
L [mH]	0.145	0.200	0.324
Exponentiality [%]	0.001	0.03	0.02

(B)

T [°C]	70	90	110
L [mH]	0.324	0.333	0.342
Exponentiality [%]	0.01	0.02	0.02

III. Possible Applications of the Illustrated Transducers

For industrial applications, at present, the use, manly, of the temperature-capacitance transducer appears profitable as, humidity sensor [2] and as heat meter [6] to calculate the heat consumption from the heating warm

IV. Test Results

Experimental of the illustrated transducers, namely, a temperature-capacitance and inductance transducer has been developed. -*Prototypes' rated data*: - mercurial thermometer, temperature range from 0 °C to 120 °C capillary, length 155 mm, inner and outer diameter, 1 mm and 1.7 mm, glass thickness, 0.35 mm. – Temperature -capacitance transducer the outer surface of the capillary of mercurial thermometer has been coated by AL and shielded.- - Temperature -inductance transducer on the outer surface of the capillary of the mercurial thermometer in the range 0-120 °C has been wound a coil of 453 wires (about 3 wires per millimeter). The coil has been shielded for the whole length by a cylinder of iron having 8 mm and 11 mm of the inner and outer diameters.

Two tests have been performed on each of these prototypes, the first one has been an highly accurate detection by a ratio transformer bridge (linearity of the ratio arms 0.5 ppm) and the second one, in factory test conditions, by a two wires double ac currents transmitter, with as inputs the two ac currents through e.g. C_x and C_c , and as outputs two dc currents proportional to the two ac inputs. As differential output has been adopted the voltage difference between the voltage drops on two resistors series connected with the two output dc currents. By the ac currents transmitter, with C_x and C_c supplied in parallel with the same ac voltage of 15 V at 5 kHz, an output voltage of 5 V dc has been obtained with a sensitivity of 10 mV/pF or about 42 mV/°C and 1.3 mV/°C respectively in the range of temperature 0-20°C and 40-120 °C. The characteristic of capacitance- temperature is illustrated in Fig 2 and Tab 1. The characteristic of self-inductance related to temperature can be approximated by a linear regression of capacitance (C) to temperature (T). With $C=mT+b$. (A) in the range of temperature 0-20 °C, is $m \cong 4.2 \text{ pF/}^\circ\text{C}$, $b \cong 50 \text{ pF}$, $1-r \cong 410^{-7}$, linearity $\cong 0.03 \%$. (B) In the range of temperature 40-120 °C, is $m \cong 0.13 \text{ pF/}^\circ\text{C}$, $b \cong 155 \text{ pF}$, $1-r \cong 810^{-5}$, linearity $\cong 0.04\%$. The Characteristics of inductance to temperature are illustrated in Fig 3 and Tab 2. The characteristic of inductance (L) related to temperature (T) can be approximated by an exponential regression of inductance to temperature in two ranges of temperature. With $L=be^{mT}$. (A) In the range of temperature 20-70 °C, $m \cong 0.016 \text{ mH/}^\circ\text{C}$, $b \cong 0.1 \text{ mH}$, $1-r < 210^{-7}$, exponentiality 0.03%. (B) In the range of temperature, 70-120 °C, $m \cong 1.310^{-3} \text{ mH/}^\circ\text{C}$, $b \cong 0.3 \text{ mH}$, $1-r \cong 410^{-7}$, exponentiality 0.03%.

V. Conclusions

The illustrated industrial temperature capacitive and inductive transducers by an HG thermometer implement the capacitance and inductive transducers' field to temperature measurements, at present, losing. Moreover these transducers have shown to respond to the necessity, in the industrial environment, for combining accuracy with the simplicity and product durable life. Which makes for reliability.

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Biographies

FRANCO CASTELLI was born in Milan, Italy. He received the M.S. degree in electrical engineering from the "Politecnico di Milano", Milano, in 1958. He worked one year at C.G.E. (Compagnia Generale di Elettricit ), Milan, in the servomechanism field. In 1961 he joined the Polytechnic of Milan as Assistant Professor of Electrical Measurements. He was awarded the "Angelo Barbagelata" premium in 1965 and the "Lorenzo Ferraris" premium in 1967 on the basis of the publications on electrical measurements. In 1971 he has been qualified for university teaching, on "Electrical Measurements". Since 1974 he has been an Associate Professor of "Advanced Electrical Measurements" at the Polytechnic of Milan. He has published various aspects of electrical measurements.

MARCO FAIFER was born in Bormio (Italy) on July 28, 1978. In 2003 he received his M.Sc. degree in Electronic Engineering at the Politecnico of Milan. Currently he is an assistant professor of Electrical and Electronic Measurements at the same University. His scientific activity is mainly concerned with the DSP techniques, the development of industrial sensors and the devices for High Voltage measurements.