ISSN 1392-2114 ULTRAGARSAS, Nr.3(56). 2005.

Temperature dependence of a piezoceramic transducer electric impedance

V. Petkus, A. Ragauskas, P. Borodičas

Telematics Scientific Laboratory, Kaunas University of Technology

Introduction

Typically, the temperature dependence of a piezoceramic transducers impedance has a negative influence on the metrological characteristics of the devices for ultrasonic flow and level measurement. The effect of temperature influence not only stipulates the impedance mismatching between the ultrasonic transducer and electronic part of the measuring device which can cause undesired phase shifts during the reception and transmission of ultrasonic signals, but also acts on physical properties of the material, the physical quantities of which are measured. The uncompensated temperature-dependent changes of physical properties of the material (such as viscosity, ultrasound speed, ultrasound attenuation) can influence the methodological errors having a systemic behavior. It is very important to evaluate the changes of these physical properties in developing wide dynamic measurement range ultrasonic flowmeters which have to perform precise flow rate measurements of the fluid flowing in turbulent, laminar and intermediate regimes within fluid temperature ranges from 0 to 120°C and above. For such meters it is especially important to evaluate the temperature-dependent change of fluid kinematic viscosity which changes a few times (about 5 times for water) within this temperature ranges. It affects the temperature-dependent shift of the intermediate regime between the turbulent and laminar flow where the flow correction factor used for calibrating typical ultrasonic one-chordal path flowmeters changes by over 20% [1, 2]. To solve this problem, the temperature compensation is needed. The common methods for compensation of temperature influence in ultrasonic flow or level measuring devices are the following:

- by applying temperature measuring channel with the temperature sensor (temperature resistance, thermocouples, etc.) [3].
- by implementing the measurement of temperature-dependent acoustic properties of the material (ultrasound velocity and attenuation) [4,5],
- by measuring temperature-dependent changes of a piezoceramic transducer resonance frequency [6,7].

In this work we present the alternative temperature determination method based on the measurement of temperature-dependent electric impedance or capacitance changes of ultrasonic piezoceramic transducer. Although this method is mentioned in a few sources [8, 9], it is not well investigated and used in practical applications. The attraction of such a method is that no additional measuring channel or temperature sensor is needed, because the same ultrasonic transducers can be used as temperature sensors. Another attractive peculiarity is that the indirect impedance or capacitance measurement can be easily implemented in time-of-flight ultrasonic measurement devices.

The aim of this work is to investigate the temperature dependence of an electric impedance and an electric capacitance of ultrasonic piezoceramic transducers with the purpose to apply this effect in ultrasonic measuring devices for the compensation of temperature-dependent changes of physical properties of the material influencing the measurement results.

Method

A few types of cost effective PZT piezoceramic transducers that are used in newly developed ultrasonic flowmeters were chosen to explore their temperature-dependent electric impedance characteristics. Disk shape piezoceramic transducers were made from PIC155 type piezoelectric material ("PI Ceramic", Germany) with a high piezoelectric coupling factor, low mechanical quality and small temperature dependence of the dielectric permittivity [10]. The diameter of piezoceramic discs was 12 mm, the thickness was 1 mm, the resonance frequency was 2MHz. The transducers for the investigation were prepared in different ways:

1 - four transducers - without preparation, without housing, without matching layer (Fig. 1a),

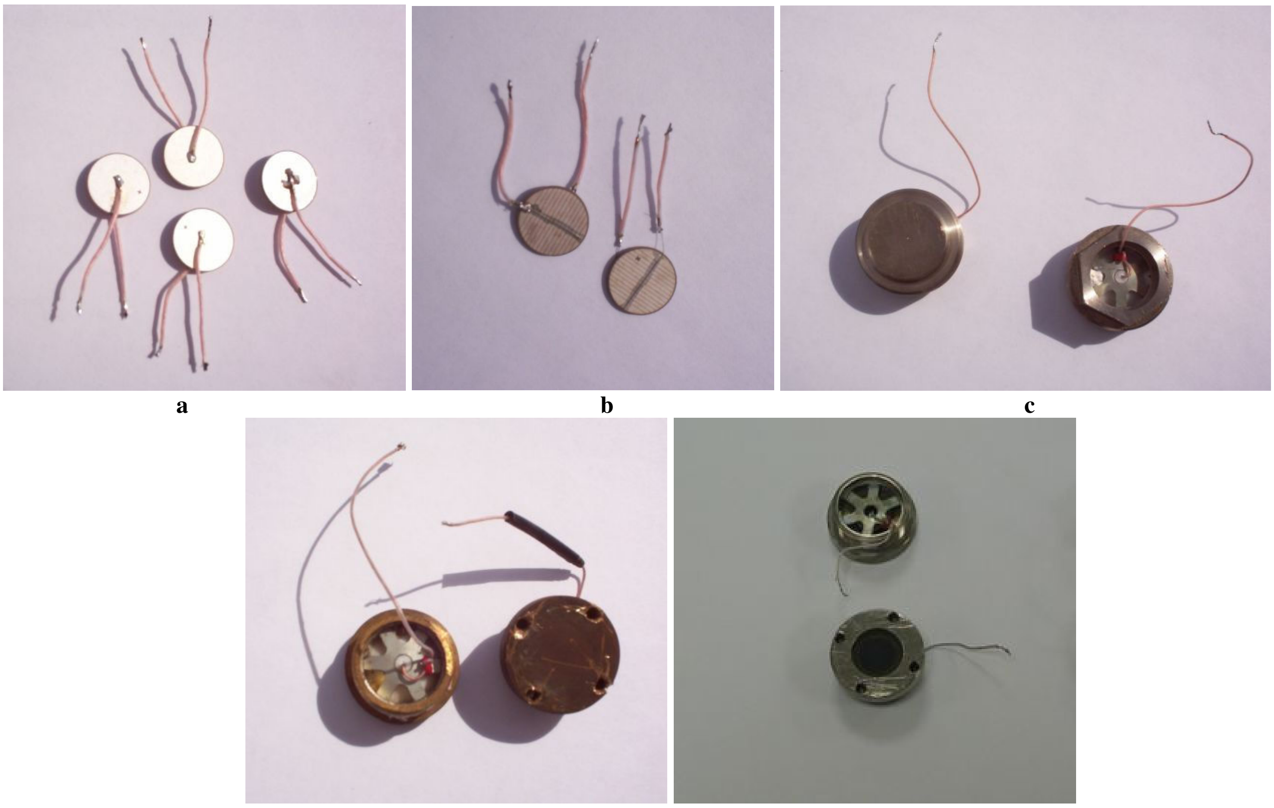
2 - two transducers – diced ceramic, without housing, without matching layer (Fig. 1b),

3 - two transducers – diced ceramic, with a titanium housing and one side titanium matching layer with $\lambda/4$ thickness and the acoustic impedance of 27,3 kg/s m² [11] (Fig. 1c),

4 - two transducers – diced ceramic, with brass housing and one side brass matching layer with $\lambda/4$ thickness and the acoustic impedance of 37 kg/s·m² [11] (Fig. 1d),

5 - two transducers – non-diced ceramic, with a housing and one side special compound matching layer with $\lambda/4$ thickness and the acoustic impedance of 6,3 kg/s·m² value (Fig. 1e). The transducers of 3, 4 and 5 types with housings were damped applying the PTFE material.

The transducers were placed in the heating camera where their electric impedance was measured over the frequency range from 0.5 MHz to 4 MHz at a temperature values of T=20±5°C; T=70±5°C; T=140±5°C. Such temperature range was chosen taking into account the requirements for typical ultrasonic flow/heat meter application conditions. Additionally, the electric capacitance was measured at every temperature using LRC multimeter.



a b c d e

Fig. 1. **The cost effective piezoceramic transducers used for temperature-dependent electric impedance investigation: a – piezoceramic transducers without special preparation; b - diced piezoceramic transducers without matching layer; c - diced piezoceramic transducers with a housing and a titanium matching layer; d - diced piezoceramic transducers with a housing and a brass matching layer; e – non-diced piezoceramic transducers with a housing and a special compound matching layer**

Results and discussion

The measured temperature dependences of the electric impedance module and electric capacitance for each type of the investigated piezoceramic transducers are shown in Fig. 2 and Fig. 3 respectively. The measured impedance data are marked with asterisks for the temperature T=20±5°C, with squares for the temperature T=70±5°C and with diamonds for the temperature T = 140±5°C in Fig 2. The data representing each piezoceramic disk within 5 transducer groups are numbered in 1, 2, 3, 4 (in Fig. 2a) and 1, 2 (in Fig. 2b-2e). By comparing the results presented in Fig 2 it is clearly seen that all the types of the investigated piezoceramic transducers have a common temperature-dependent behavior of an electric impedance within the frequency range from 0.5 MHz to 1MHz which is characterized by decreasing the electric impedance by about 1,5-2 times when the temperature of the piezoceramic discs increases from 20° to 140°C. At higher frequencies, however the temperature dependence of the electric impedance of the transducers does not have common and clearly expressed behavior. The effect of the decreasing impedance at lower frequencies, when the temperature increases, is related to the capacitance dependence on a temperature which has been found to be linear for the piezoceramic transducer with a matching layer (Fig 3d-3e) and logarithmic for the piezoceramic transducer without a matching layer (Fig 3a, 3b).

For better representation of the relationship between the measured electric impedance module and temperature, the experimental data have been repotted for the frequency ranges from 0.5 MHz to 1 MHz and shown in Fig 4. The results shown in Fig. 4 demonstrate that the electric impedance decreases linearly when the transducer temperature increases from 20°C to 140°C at a fixed frequency within the frequency range from 0.5 MHz to 1MHz. By applying this effect for evaluation of the temperature, the sensitivity could be better achieved at a lower frequency for the non-diced piezoceramic transducer ($\Delta Z / \Delta T$ = -0.79 Ω/ °C at 0.5 MHz for transducers without a matching layer (Fig. 4a) and $\Delta Z / \Delta T$ = -0.88 Ω/ °C at 0.5 MHz for transducers with a matching layer in Fig. 4e and for transducers with a matching layer having a lower acoustic impedance (Fig. 4c, 4d and 4e).

Conclusions

1. The results of experimental investigation show that there is a possibility to evaluate temperature by measuring the electric impedance and capacitance of a piezoceramic transducer. For all types of the investigated piezoceramic transducers a common behavior of an electric impedance which linearly decreases about 1.5…2 times when the temperature increases from 20° to 140°C degrees within the frequency range below a resonance frequency (from 0.5 MHz to 1MHz) have been found.

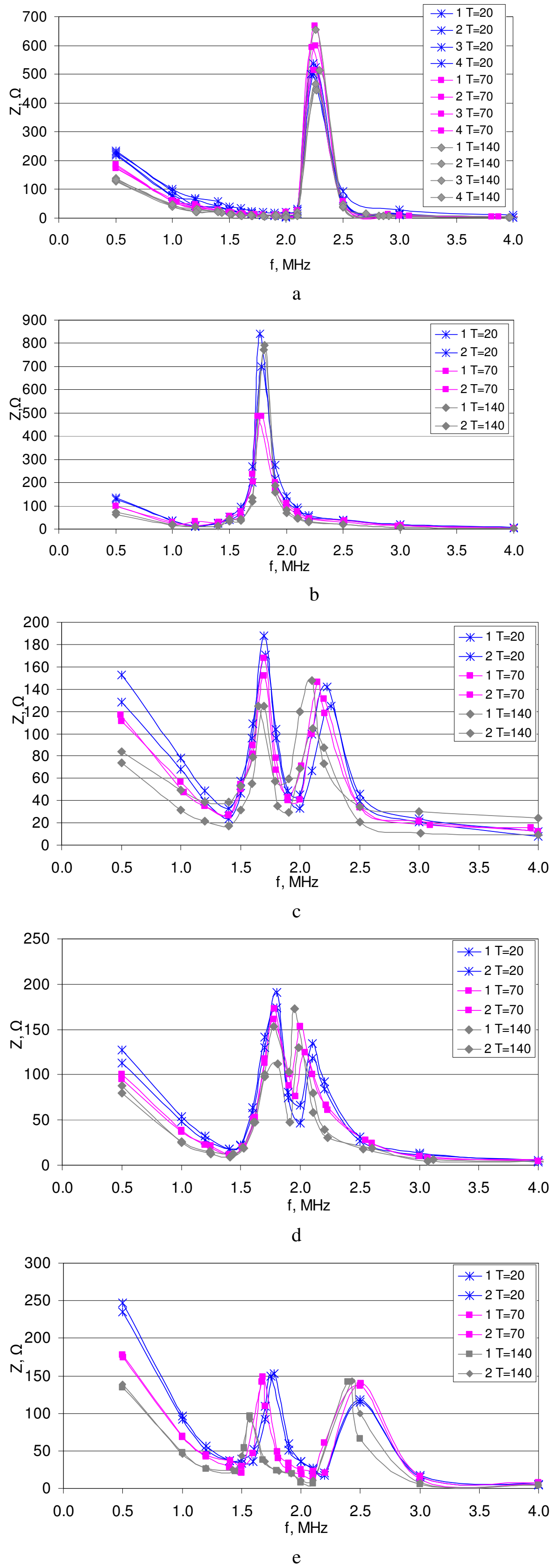


Fig. 2. **The measured temperature dependences of the electric impedance module for 5 groups of piezoceramic transducers: a – piezoceramic transducers without special preparation; b - diced piezoceramic transducers without a matching layer; c - diced piezoceramic transducers with a housing and a titanium matching layer; d - diced piezoceramic transducers with a housing and a brass matching layer; e – non-diced piezoceramic transducers with a housing and a special compound matching layer.**

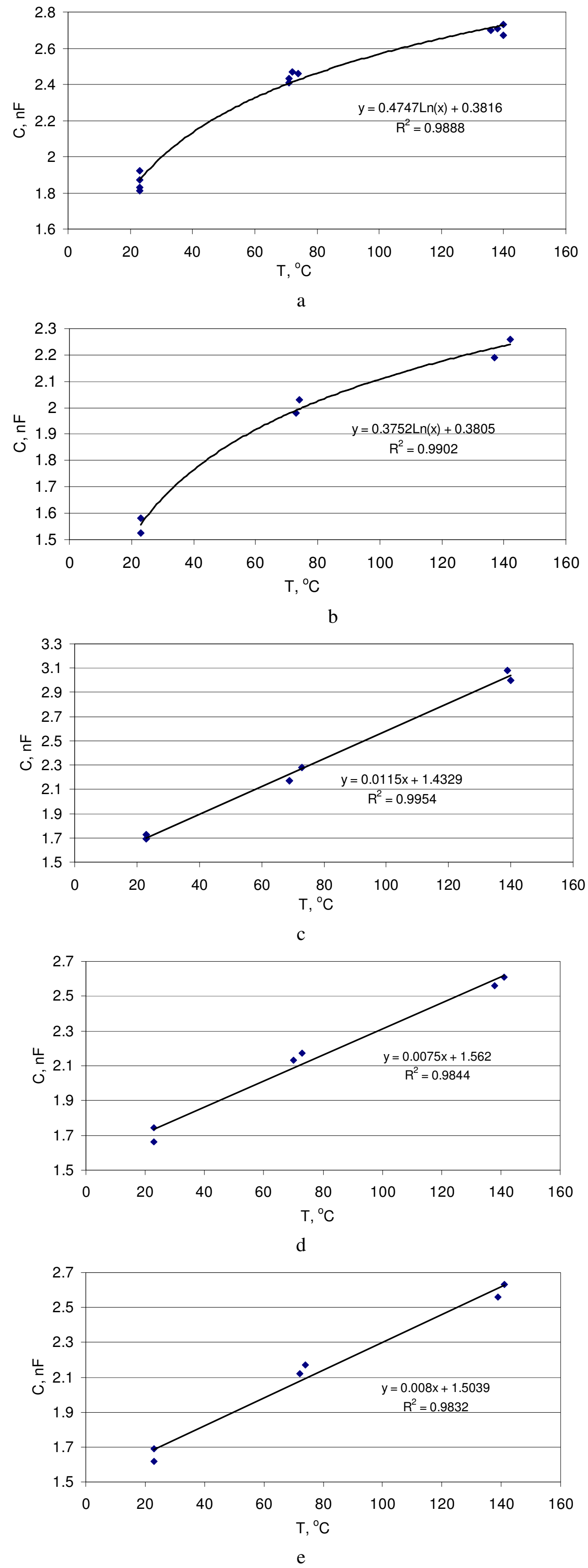
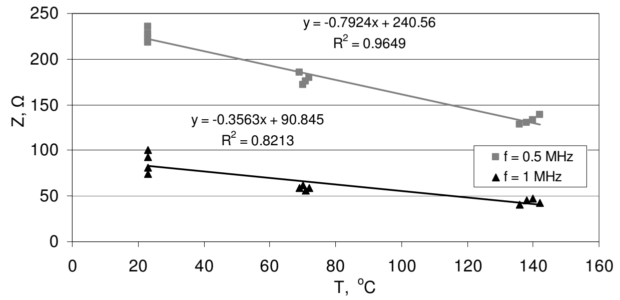
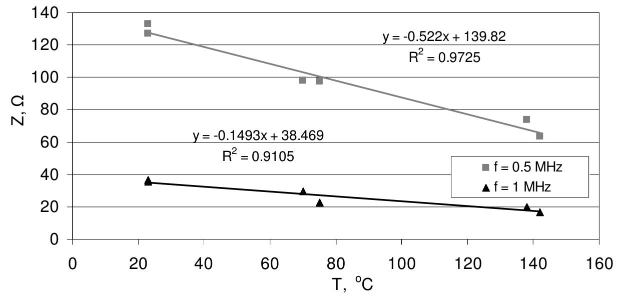


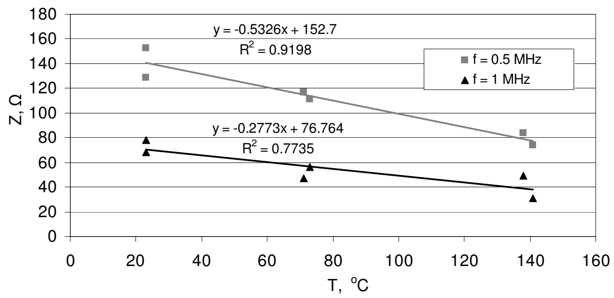
Fig. 3. **The measured temperature dependences of the electric capacitance for 5 groups of piezoceramic transducers: a – piezoceramic transducers without special preparation; b - diced piezoceramic transducers without a matching layer; c - diced piezoceramic transducers with a housing and a titanium matching layer; d - diced piezoceramic transducers with a housing and a brass matching layer; e – non-diced piezoceramic transducers with a housing and a special compound matching layer.**



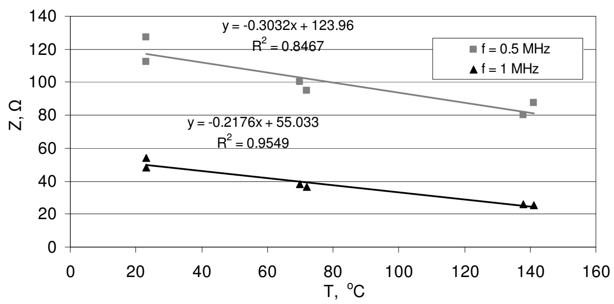
a



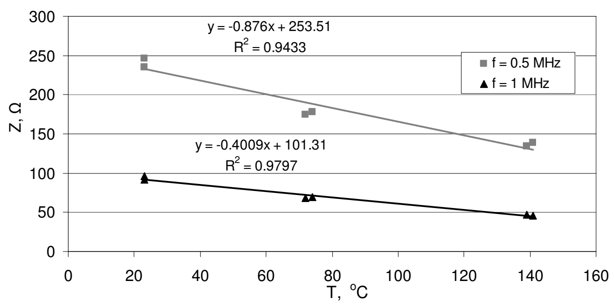
b



c



d



e)

Fig. 4. **The measured temperature dependences of the electric impedance at 0,5 MHz and 1 MHz frequency for 5 groups of piezoceramic transducers: a – piezoceramic transducers without special preparation; b - diced piezoceramic transducers without a matching layer; c - diced piezoceramic transducers with a housing and a titanium matching layer; d - diced piezoceramic transducers with a housing and a brass matching layer; e – non-diced piezoceramic transducers with a housing and a special compound matching layer.**

1. The highest temperature measurement sensitivity ($\Delta Z / \Delta T$ = -0.88 Ω/ °C at 0.5 MHz and $\Delta Z / \Delta T$ = -0.40 Ω/°C at 1MHz) has been found for non-diced piezoceramic transducers with a matching layer having a lower acoustic impedance with the value of 6.3 kg/s·m² (Fig. 4e).

2. The investigated capacitance dependence on a temperature has been found to be linear for piezoceramic transducers having a matching layer (Fig 3d – 3e) and logarithmic for piezoceramic transducers cases without a matching layer (Fig 3a, 3b).

3. This effect could be applied in the ultrasonic flow, level or other meters for correction of the temperature-dependent systematic errors without applying any additional temperature measuring channels and temperature transducers, because the same ultrasonic piezoceramic transducers can be used as temperature sensors.

References

1. **Spoor H. L., Oldenziel D. M**. On the ultrasonic flow measurements in realation to the Reynolds number and finite sensor sizes. Flow Measurement Flomeko -, VDI Berichte. 1989. Nr. 768. P. 181-197.
2. **Spitzer D. W., Boyes W.** The consumer guide to ultrasonic and correlation flowmeters. Spicer and Boyes LLC. New York. 2004. P.64.
3. **Wiest A.** Ultrasonic flow meter with temperature compensation provided by temperature sensor in parallel with ultrasonic measurement transducers. Patent DE10057188. 2002.
4. **Takayama K.** Flow meter and monitoring system of flow rate measurement. Patent JP2001201377. 2001.
5. **Sonnenberg H. M.** Measurement of mass flow rate of liquids or gases using an ultrasonic transducer, with use of additional pressure gauges enabling determination of fluid density, temperature or viscosity. Patent DE10062875. 2002.
6. **Fletcher-Haynes P.** Method and apparatus for correcting temperature variations in ultrasonic flowmeters. Patent US5831175. 1998.
7. **Hazelden R. J., Smith K.P.F.** Improvements in fluid monitoring. Patent WO2004070358. 2004.
8. **Ralf S., Russel W.** Ultrasound transducer temperature compensation methods, apparatus and programs. Patent US2004064280. 2004.
9. **Koichi T., Yutaka I.** Ultrasonic flow meter. Patent JP10239123. 1998.
10. Piezoelectric Ceramics & Components. PI Ceramic. www.piceramic.de
11. Table of ultrasonic properties. X Actex Corp. 1995

V. Petkus, A. Ragauskas, P. Borodičas

Temperatūrinė pjezokeraminio keitiklio elektrinio impedanso priklausomybė

Reziumė

Darbe parodyta, kaip galima nustatyti temperatūrą matuojant pjezokeraminio keitiklio elektrinį impedansą ir elektrinį talpį. Ištirtos įvairių pjezokeraminių keitiklių, naudojamų ultragarsiniuose srauto jutikliuose, elektrinio impedanso ir talpio priklausomybės nuo 20^0...140°C temperatūrų intervale. Tyrimo rezultatai parodė, kad visų tyrime naudotų pjezokeraminių keitiklių impedanso temperatūrinė priklausomybė žemesniame nei rezonanso dažnių diapazone (nuo 0,5 MHz iki 1MHz) turi bendrą dėsningumą: elektrinis impedansas tiesiškai mažėja apie 1,5-2 kartus kintant keitiklio temperatūrai nuo 20° iki 140°C. Nustatyta, kad didesnis temperatūros matavimo jautris pasiekiamas matuojant elektrinį impedansą žemesniuose dažniuose (žemesniame nei keitiklio rezonanso dažnis). Didžiausias temperatūros matavimo jautris pasiektas naudojant pjezokeraminius keitiklius su mažos banginės varžos suderinimo sluoksniu. Šis efektas gali būti pritaikytas ultragarsiniuose srauto, lygio ar kituose matavimo prietaisuose, kuriuose be jokių papildomų temperatūros matavimo kanalų ar temperatūros jutiklių galima būtų įdiegti nuo temperatūros priklausomų sisteminių paklaidų korekciją.

Pateikta spaudai 2005 06 20