Joint **IMEKO TC-1 & XXXIV MKM Conference 2002**
Wrocław, 8 - 12 September 2002

Stanisław WALUŚ*
Janusz ŻELEZIK*

THE MASTER'S THESES ON THE ESTIMATION OF METROLOGICAL PROPERTIES OF MEASURING INSTRUMENTS ON THE BASE OF THE EXPERIMENTAL INVESTIGATIONS AND THE MATHEMATICAL MODELLING

The students of the Department of Automatic Control, Electronics and Computer Science are preparing their master's theses in Measurement Systems Group of Institute of Automatic Control. They include the experimental investigations in Institute laboratory of various measuring instruments and also the mathematical modelling of primary devices of flowmeters and other instruments. Some results of master's theses were published in Polish scientific newspapers and in international conference proceedings. The measurement system for identification dynamic model of thermometers by "in-situ" method was elaborated. The measurement system enables identification of dynamic models of resistance thermometers by three methods: classical step-input method and two in-situ (internal input) methods. The mathematical modelling of distorted velocity distributions enables the investigation of errors of sampling flowmeters. On the base of the experimental data from rivers the modelling investigations for sampling flowmeter used for open channel were made.

Key words: laboratory investigations, mathematical modelling, dynamic properties of thermometers, education.

1. INTRODUCTION

The students of the Department of Automatic Control, Electronics and Computer Science are preparing their master's theses also in the Measurement Systems Group of Institute of Automatic Control [32]. A lot of these theses include the experimental investigations of various measuring instruments in Institute laboratories and also the

*Silesian Technical University, Institute of Automatic Control, Measurement Systems Group, ul. Akademicka 16, 44-100 Gliwice, Poland, e-mail: swalus@oak.ia.polsl.gliwice.pl, jz@oak.ia.polsl.gliwice.pl

mathematical modelling of primary devices of flowmeters or other instruments.

Students of line automatic control and robotics were taking part in scientific camps and in industrial practices in steel works, water-supply system and in Institute for Meteorology and Water Control and Exploitation (Warszawa) as well in firm SONIX (Warszawa) producing ultrasonic flowmeters. Some of them elaborated their masters' theses on themes connected with these institutions. The second source of masters' theses was the need of development of flow measurement laboratory. For industrial measurement laboratory the measurement system for identification dynamic model of thermometers by "in-situ" method was elaborated.

2. FLOW MEASUREMENT LABORATORY

In the frame of the industrial measurement laboratory [20] are laboratories for flow, temperature, pH, gas chromatography, strain, pressure and isotope radiation measurements. The measuring installation in flow laboratory was build up with students' works. This laboratory is for laboratory classes for students of two lines: 1) automatic control and robotics, 2) electronics and telecommunication. The installation was made for this minimal goal but in such way, that to enable its further development. Now it consists of three measuring systems: 1) for air flow measurements, 2) for calibration of water flowmeters, 3) for measuring data gathering and processing. The first installation enables the measurement of flow-rate with help of orifice plate. The second installation enables the calibration of water flowmeters according to [25]. The accuracy of calibration depends on many factors, mainly on the value of flow-rate q and on the time of filling the measuring tank t. The results of calculation according to equation (1) were made for Δt = 0,3 s and for $\Delta_{\Delta h}$ = 1 mm and are shown in fig. 1. The relative uncertainty of volume flow-rate q measurement can be calculated from:

$$\delta_q = \sqrt{\left(\frac{0{,}2069\ \mathrm{m}^2\ \Delta_{\Delta h}}{q\,t}\right)^2 + \left(\frac{\Delta_t}{t}\right)^2 + (0{,}05\%)^2}, \qquad (1)$$

where: $\Delta_{\Delta h}$ - uncertainty of difference of liquid level measurement, Δt - uncertainty of t measurement, 0,05% - uncertainty of calibration of measuring tank.

The further theses were connected with the construction of the diverter [23], ultrasonic flowmeter for pipes with small diameters [21], evaluating of the tracer method [18] and evaluating of Coriolis flowmeter [4]. The air flow-rate measuring installation was used for averaging impact tubes investigations [5, 7]. The system for measuring data gathering and processing was based on the BITBUS interface and prepared with DOS system [8]. Further works connected with evaluation of metrological properties of this system [13, 27] were assumed in publications: [9, 12, 33].

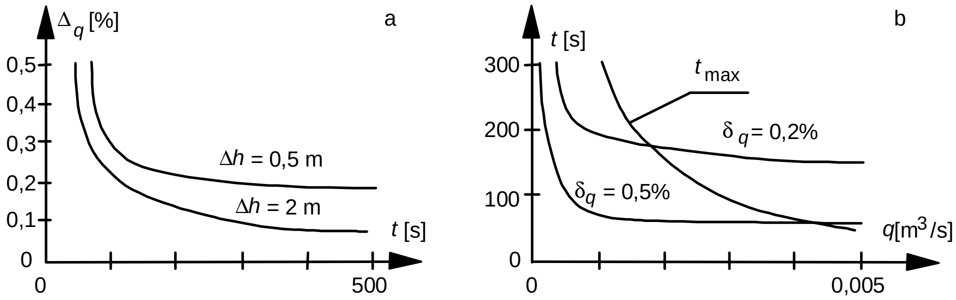

Fig. 1. Measurement possibilities of calibration system: a - error as a function of the time of filling the measuring tank, b - time of filling the measuring tank as a function of flow-rate

3. LABORATORY INVESTIGATIONS OF METROLOGICAL PROPERTIES OF CHOSEN METHODS OF FLOW PARAMETERS MEASUREMENT

The Coriolis flowmeter was checked for mass flow-rates of water to 11 t/h [4]. Endress-Hauser flowmeter was installed in adopted laboratory installation. The intrinsic relative error declared by the producer was 0,25%, the span of 15 t/h. The flowmeter was tested for mass flow-rates from 0,65 t/h to 11 t/h. For the span of flow-rates 3,3 t/h to 11 t/h the relative error was changing from -0,07% to 0,11%, what fulfil data given by the producer. For smallest flow-rates the relative errors were about 5% and decreased for higher flow-rates. The Coriolis flowmeter is declared as independent from velocity distribution distortion, but during laboratory investigations the influence of an orifice plate placed just before the flowmeter was tested. The measurements were made for flow-rate of 3 t/h for four orifice plates: two concentric orifices with cross-sectional area of the hole to the pipe cross-sectional area m = 50% and 70%, and for segmental orifices with m = 50% and 70%. The maximum error for segmental orifice was 2,5% and for concentric orifice 0,6%. The results of these investigations were published in [29].

Two kinds of tracer method: transit time method and dilution method were investigated in laboratory of flow measurement [20] in the frame of work [18]. The laboratory installation was equipped with open channel with half-circle cross-section, apparatus for giving the tracer in dilution and in transit time method. The influence of the setting of the electrode for the measuring error and the calibration curve was estimated. The influence of the distance between the electrodes and between the place of injecting of the tracer and the first electrode were investigated and optimal parameters were chosen. The reference flow-rate was measured with volumetric method.

The averaging impact tube was tested in purpose to estimate the tube coefficient and the influence of the cross-section shape of the tube for sensitivity factor [5, 7]. The flow rate was measured with orifice plate. There were made four tubes with cross-section shapes which are used by firms: Accutube, Honeywell, Presto and Veris [7]. For the maximum flow-rate the output differential pressure signals from tubes were 429, 539, 376 and 368 Pa correspondingly. Also the influence of the position angle for sensitivity was investigated. The results of laboratory investigations were published in [30]. In the frame of [5] the value of the tube coefficient was estimated on the base of velocity distribution shape estimation (with Prandtl formula and two other models).

Ultrasonic flowmeters are typical sampling flowmeters, for which the flow-rate can be calculated on the base of velocity measurements in some segments in the flow area. The possibility of testing of ultrasonic flowmeter with help of velocity area method was investigated in the flow laboratory in the Institute of Meteorology and Water Control and Exploitation in Warsaw [10]. The point velocity was measured with insertion turbine meter, which was previously calibrated on the channels with stagnant water. The flow-rate in the open channel was measured by the triangular overfall. Some results of these investigations were published in [31].

In the frame of masters' thesis [17] the velocity distributions in the 200 mm diameter pipe were investigated with impact tube in the laboratory of Industrial Institute of Automatic Control and Measurement in Warsaw. The goal of the masters' thesis [21] was to adopt the ultrasonic flowmeter of firm Ultraflux to the flow-rate measurement in the pipe of small diameter in the students laboratory. In the next master' thesis [26] the primary device of ultrasonic flowmeter simulator was constructed and on the base of analysis of operation of the secondary device was tested.

4. IDENTIFICATION OF DYNAMIC MODEL OF THERMOMETERS

Investigation of dynamic properties of measuring instruments is very important, especially in the Automation Control Department. Estimation of dynamic model of measuring instrument is important not only for evaluation of his dynamic error, but the measuring instrument is the part of automatic control system and its dynamic and dynamics of the object influence on a controller choosing, control quality and stability of the whole control system. Thermometers are good example of measuring instruments for identification of dynamic properties [22].

Masters' theses [6, 11] concerned elaborating of the measuring system and investigation of various methods of dynamic models of contact thermometer, especially resistance thermometer (RTD) and thermocouples. Students investigated two base methods of identification: classical method – the input temperature step response and "in-situ" method. The second method can be used in the place of thermometer installing

- in real working conditions. The classic method demands simple measuring system and the procedure of parameter (first or second order inertia or inertia with delay time) are relatively simple. It is the laboratory method and it is the problem of extrapolation of model parameters to real conditions in the place of sensor installation. The second method does not have this weakness, because the identification is done on the object, but the problem of identification is more complicated. The response of the sensor is investigated against the changes of the power supplied directly to the sensor - with additional hitting current. Two methods were investigated: loop current step response (LCSR method) and using of multifrequency input binary signals (MBS method).

In comparison with classic method the system for "in-situ" identification must include not only hardware for the output signal acquisition, but also the equipment for generation of variable current, which heats the sensor. It is more difficult to realise it for thermocouples than for resistance sensors because the thermocouple resistance is very small, and the heating current disturbs the measurement of thermocouple voltage. The periodically switching on and switching off heating current is used. The heating is switch off while the temperature is measured.

The MBS method is better than LCSR method because of use of binary bias signal, which is easy to be generated and the power is concentrated in some first harmonics. In this method the time of the identification experience is briefer but it allows more accurate estimation of model parameters. In the fig. 2 are examples of signals during experimental identification of resistance thermometer with simple construction.

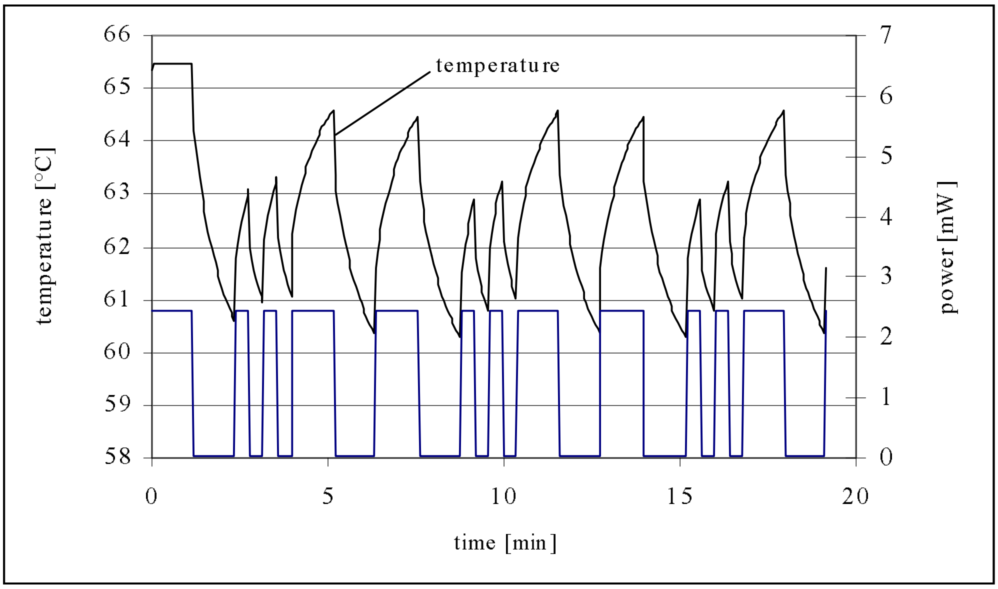

Fig. 2. The measuring data from 10 mm diameter thermometer during estimation of dynamic model with help of "in-situ" method and MBS 3311 signals using

The fault of "in-situ" identification method is that instant of the dependency between the medium and the sensor temperatures are estimated another model: between the additional heating power and the sensor temperature. Detailed analyses showed, that for simple sensor, which can be described with first order inertia, both models are analogous, but for more complicated construction there is possible to conclude about the input-output dynamic thermometer model on the base of model, which was estimated with "in-situ" method.

5. ESTIMATION OF METROLOGICAL PROPERTIES OF SAMPLING FLOWMETERS ON THE BASE OF THE MATHEMATICAL MODELLING

The mathematical modelling of distorted velocity distributions enables the investigation of errors of sampling flowmeters. Calculation procedure can be used for various velocity sensors used in sampling flowmeters. One-path and multi-path ultrasonic flowmeters were modelling in masters' theses [15, 17]. In [17] were used experimental data taken from the 0,2 m pipe diameter. In [1, 15] some mathematical models of distorted velocity distributions were used to calculate errors of flowmeters in the conditions other than normal and the results were published in [2, 16].

The simulation of primary device of flowmeter with one point velocity measurement was done in masters' thesis [14]. The influences of distorted velocity distribution on the error of flow-rate measurement were investigated.

The most difficult and also most valuable is the mathematical modelling of sampling flowmeter primary device for flow-rate measurement in open channels. Mathematical modelling of one-path ultrasonic flowmeters for open channels were introduced in [35]. In masters' thesis [3] on the base of the experimental data from rivers the modelling investigations for sampling flowmeters used for open channels were made and many typical models of velocity profile in horizontal and vertical axis were checked on the base of experimental data. Mathematical modelling of ultrasonic multi-path flowmeters for open channels (for various flow conditions and various flow cross-section) is introduced in [19, 28] and some results are published in [34].

6. CONCLUSIONS

Experimental investigations are very important in metrology; not only because of estimation of measuring instrument characteristic, but also in purpose to know, how the instrument performs in various conditions of measurement.

Sometimes physical modelling of real conditions of measuring instrument performance is very difficult (the dimensions of object, costs, long time of preparing installation, extreme measuring conditions) and in these situation the mathematical modelling is very useful.

Investigations of static and dynamic properties of measuring instruments are very important from metrological point of view. Dynamic properties are essential also for the performance of closed control system, for example for its stability.

Some results of master's theses were published in Polish scientific newspapers [29, 31, 33] and in national [9, 12, 16, 30, 36, 37] and in international conference proceedings [2, 34].

REFERENCES

[1] ALBIŃSKI A.; *Badania modelowe przepływomierza ultradźwiękowego w warunkach odbiegających od normalnych*, praca dyplomowa, Instytut Automatyki, Gliwice 1990.

[2] ALBIŃSKI A., WALUŚ S., ŻELEZIK J.; *Estimation of One-Path Ultrasonic Flowmeter Characteristic for the Case of Distorted Velocity Distribution*, Proceedings of the 2nd Brazilian Symposium on Flow Measurement, March 20-24, 1995, Sao Paulo - Brazil, 127-134.

[3] BARTYZEL D.; *Badania modelowe przepływomierzy próbkujących do pomiaru strumienia objętości wody w przewodach otwartych z wykorzystaniem danych doświadczalnych*, praca dyplomowa, Instytut Automatyki, Gliwice 2001.

[4] BRZĘCKI J.; *Właściwości metrologiczne i eksploatacyjne przepływomierzy Coriolisa*, praca dyplomowa, Instytut Automatyki, Gliwice 1995.

[5] CZESZYK G.; *Badania doświadczalne i modelowe uśredniających rurek spiętrzających*, praca dyplomowa, Instytut Automatyki, Gliwice 2001.

[6] ĆMIEL T.; *Wyznaczanie własności dynamicznych termometrów metodą in situ...*, praca dyplomowa, Politechnika Śląska, Wydział AEiI, Gliwice 1997.

[7] DANES M.; *Opracować program do doboru parametrów i analizy błędów pomiaru uśredniającej rurki spiętrzającej*, praca dyplomowa, Instytut Automatyki, Gliwice 1997.

[8] GRAJEWSKI M.; *Automatyzacja stanowiska laboratoryjnego do badania przepływomierzy, praca dyplomowa*, Instytut Automatyki, Gliwice 1993.

[9] GRAJEWSKI M., BORSUK M., WALUŚ S.; *Zastosowanie systemu BITBUS do zbierania i przetwarzania danych pomiarowych na stanowisku badawczym przepływomierzy*, Konferencja AUTOMATION'97 5-7 marca 1997, Warszawa, PIAiP, Referaty tom 2, Warszawa 1997, 453-460.

[10] GROLIK E.; *Zaprojektować stanowisko wzorcowe do badań przepływomierzy w kanałach otwartych z wykorzystaniem przepływomierza turbinowego typu sonda*, praca dyplomowa, Instytut Automatyki, Gliwice 1983.

[11] GRYC R.; *Ocena różnych metod identyfikacji dynamiki termometrów*, praca dyplomowa, Politechnika Śląska, Wydział AEiI, Gliwice 1999.

[12] JASIŃSKI M.; *Automatyzacja zbierania i przetwarzania danych na stanowisku badawczym przepływomierzy*, XXIX MKM'97, Nałęczów, 10-12 września 1997 r., Politechnika Lubelska, Lublin 1997, Materiały Konferencyjne, Tom 1, 179-186.

[13] JASIŃSKI M.; *Automatyzacja zbierania i przetwarzania danych na stanowisku badawczym przepływomierzy*, praca dyplomowa, Instytut Automatyki, Gliwice 1997.

[14] JĘDRASIK P.; *Badania modelowe wpływu zniekształconych rozkładów prędkości na błędy przepływomierzy próbkujących*, praca dyplomowa, Instytut Automatyki, Gliwice 2001.

[15] KAMIŃSKA H.; *Analiza dokładności pomiaru natężenia przepływu w rurociągach przepływomierzem ultradźwiękowym w warunkach odbiegających od normalnych*, praca dyplomowa, Instytut Automatyki, Gliwice 1993.

[16] KAMIŃSKA H., WALUŚ S.; *Błędy jednodrogowego przepływomierza ultradźwiękowego występujące przy niecałkowitym wypełnieniu rurociągu cieczą*, Sympozjum Metrologia'86, Warszawa, 11-13 VI 1986, CUP MiSP, Politechnika Warszawska, Warszawa 1986, Tom II, 62-71.
[17] KONIECZNIAK D.; *Zależność właściwości metrologicznych przepływomierzy ultradźwiękowych do pomiaru strumienia objętości w rurociągu od liczby i położenia dróg fali ultradźwiękowej*, praca dyplomowa, Instytut Automatyki, Gliwice 1985.
[18] KROCZEK A.; *Wzorcowanie przepływomierzy w miejscu zabudowy metodą zastrzyku lub rozcieńczania*, praca dyplomowa, Instytut Automatyki, Gliwice 1993.
[19] KUPKA M.; *Badania modelowe przepływomierza ultradźwiękowego dla koryt otwartych przy zmiennych warunkach przepływu*, praca dyplomowa, Instytut Automatyki, Gliwice 1996.
[20] *Laboratorium Miernictwa Przemysłowego*, Frączek J., Waluś S. (ed.), Wydawnictwo Politechniki Śląskiej, Gliwice 1997.
[21] MALITOWSKi G.; *Pomiar strumienia objętości wody przepływomierzem ultradźwiękowym UF 311 w rurociągu o średnicy 50 mm*, praca dyplomowa, Instytut Automatyki, Gliwice 1991.
[22] MICHALSKI L.; *Dynamic Temperature Measurement, Proceedings Tempus Summer School "Sensor Construction,* Technologies and Sensor Systems", Gliwice 1995, 326-351.
[23] NIEZGODA I.; *Zaprojektować, uruchomić i zbadać stanowisko laboratoryjne "Pomiar strumienia objętości wody"*, praca dyplomowa, Instytut Automatyki, Gliwice 1991.
[24] PN-93/M-53950/01 *Pomiar strumienia masy i strumienia objętości płynów za pomocą zwężek pomiarowych.*
[25] PN-EN ISO 8316; 1999 *Pomiar strumienia objętości cieczy w przewodach. Metoda objętościowa.*
[26] PTASZKOWSKI P.; *Analiza błędów przetworników pomiarowych przepływomierzy ultradźwiękowych*, praca dyplomowa, Instytut Automatyki, Gliwice 1997.
[27] SZOTA W.; *Zbadać zgodność stanowiska do wzorcowania przepływomierzy wody w rurociągach z wymaganiami normy RPrPN-EN ISO 8316*, praca dyplomowa, I. Automatyki, Gliwice 1999.
[28] THOMAS A.; *Koncepcja sterowania wielodrogowym przepływomierzem ultradźwiękowym przez mikroprocesor*, praca dyplomowa, Instytut Automatyki, Gliwice 1991.
[29] WALUŚ S., BRZĘCKI J.; *Badania laboratoryjne przepływomierza Coriolisa*, Prace Komisji Naukowych, Polska Akademia Nauk, Oddział w Katowicach, Zeszyt nr 23, Katowice 1999, 41-43.
[30] WALUŚ S., DANES M.; *Dobór parametrów i analiza błędów uśredniającej rurki spiętrzającej*, Krajowy Kongres Metrologii 2001, Warszawa 24-27 VI 2001, Tom II, 661-664.
[31] WALUŚ S., GROLIK E.; *Metody sprawdzania przepływomierzy ultradźwiękowych stosowanych w kanałach i rzekach*. Zeszyty Naukowe Politechniki Śląskiej nr 847, Gliwice 1985, 205-214.
[32] WALUŚ S.; *Master's Thesis in Metrology*, Proceedings of the 2nd International seminar, Measurement Systems and Networks, Gliwice, 24-25 September 1992, Sponsored by IEEE, Poland Section, Silesian Technical University, 174-176.
[33] WALUŚ S., PACHELSKI B., SZOTA W.; *Analiza metrologiczna stanowisk do wzorcowania przepływomierzy metodą objętościową*, Pomiary Automatyka Kontrola 2001, 1, 13-15.
[34] WALUŚ S., THOMAS A., ŻELEZIK J.; *The Mathematical Model of Multi-Path Ultrasonic Flowmeter for Open Channel*, Proceedings of FLOMEKO'93, 25-29 October 1993, Seoul Korea, S.D. Park, F.C. Kingdom, Korea Research Institute of Standards and Science, 299-305.
[35] WOJNAR U.; *Modele matematyczne jednodrogowych przepływomierzy ultradźwiękowych do pomiaru strumienia objętości wody w kanałach*, praca dyplomowa, Instytut Automatyki, Gliwice 1985.
[36] ŻELEZIK J., ĆMIEL T., *System pomiarowy do badania własności dynamicznych termometrów metodą 'in-situ'*, XXX MKM'98, Pol. Szczecińska, Międzyzdroje 1998, Szczecin 1998, 553-558.
[37] ŻELEZIK J., WYŻGOLIK R.; *Wspomagane komputerowo stanowisko laboratoryjne "Pomiary Temperatury"*, XXXII MKM'98, Politechnika Rzeszowska, Rzeszów 2000, Tom 1, 163-168.