MECHANICS
Vol. 26 No. 3 2007

Grzegorz WICIAK[*], Janusz KOTOWICZ[*], Jan OKOŁO-KUŁAK[*]

INVESTIGATION AND THE DESIGN ENGINEERING OF THE STAND TO MEASUREMENT OF THE FLOW

SUMMARY

On the article one represented manners of the measurement of the flow with the weight-method. The main attention was concentrated on the method of the modifying dynamical weighing. Then one discussed the methodics of the design engineering of the stand for the measurement of the flow and calibrations with the method modified. The manner of the design engineering consists in the modelling and the analysis of the uncertainty of the measuring-system before the realization of measurement. On purpose such procedure is the selection satisfactory way of the measurement and the selection of the measuring-apparatus. Instead on purpose analyses of the uncertainty before a realization of stand measurement is the discoverment of possibly values of the uncertainty with which one ought to matter by the choice of given solution of the constructional stand and the measuring-apparatus. In the article one represented the simulatory analysis of the uncertainty before the realization of measurement, dependent from identifying disturbances affecting the accuracy of the measurement. On the article one introduced also selected results of measuring-experiments carried out on the prototype measuring-stand. The measurement became executed on purpose the verification of the assumed course of action during design-time research. The measuring-experiment confirmed that results of design-time (simulatory) investigations did not deviate from the value of results of measurement on the prototype measuring-stand.

Keywords: *weight-method, calibration, measurement of the flow*

BADANIA I PROJEKTOWANIE STANOWISKA DO POMIARU STRUMIENIA

W pracy przedstawiono sposoby pomiaru strumienia metodą wagową. Główną uwagę skupiono na metodzie zmodyfikowanego ważenia dynamicznego. Następnie omówiono metodykę projektowania stanowiska do pomiaru strumienia i wzorcowania metodą zmodyfikowaną. Sposób projektowania polega na modelowaniu i analizie niepewności systemu pomiarowego przed wykonaniem pomiarów. Celem takiego postępowania jest wybór odpowiedniego sposobu pomiaru oraz wybór aparatury pomiarowej. Natomiast celem analizy niepewności przed wykonywaniem pomiarów stanowiskowych jest ujawnienie możliwych wartości niepewności, z którymi należy się liczyć przy wyborze danego rozwiązania konstrukcyjnego stanowiska i aparatury pomiarowej. W artykule przedstawiono symulacyjną analizę niepewności przed wykonaniem pomiarów, zależną od zidentyfikowanych zakłóceń oddziałujących na dokładność pomiaru, a także wybrane rezultaty eksperymentów pomiarowych wykonanych na prototypowym stanowisku. Pomiar został wykonany celem weryfikacji przyjętego sposobu postępowania w czasie badań projektowych. Eksperyment pomiarowy potwierdził, że wyniki badań projektowych (symulacyjnych) nie odbiegają od wartości wyników pomiarów na prototypowym stanowisku.

Słowa kluczowe: *metoda wagowa, wzorcowanie, pomiar przepływu*

THE MOST IMPORTANT SYMBOLS

A	– surface of the cross section
a	– the interval of the variability
ρ	– density of water
ρ_a	– density of air
ρ_p	– density of the test weigh t
ν	– number of independent variables
c_i	– sensitivity index $c_i = \dfrac{\partial q_i}{\partial x_i}$
k	– coefficient of expansion of the total uncertainty
m	– mass of the liquid
m_0	– initial mass of the liquid in the measurement container
m_1	– final mass of the liquid in the measurement container
M, N, n	– number of measurement
N_x	– transformation function of the signal a/c
q_m	– volumetric flow
q_v	– mass flow
t	– time of filling the measurement container
U	– extended uncertainty $U = k\, u_c(x)$
$p(x)$	– the density of the probability
β	– the coefficient (edging parameter of the density of the probability)
$u_i(x)$	– estimators of the standard uncertainty
$u_c(x)$	– estimators of the total uncertainty
$u(x_i, x_j)$	– estimator of covariance
x_i or x_j	– i-th or j-th input value

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[*] Division of Measurement And Control Engineering of Power Plant Processes, Silesian University of Technology in Gliwice, Poland; Grzegorz.Wiciak@polsl.pl; Janusz.Kotowicz@polsl.pl

Additional notions

$\left(1+\rho_a\left(\frac{1}{\rho}-\frac{1}{\rho_p}\right)\right)$ – corrective coefficient[1] taking into consideration differences of the aerostatical buoyancy made by the atmosphere on weighed body and equivalent her weight of weights used at calibration of the weight-device,

$\left(1-\frac{A_{\text{dropping\_ flow}}}{A_{\text{container}}}\right)$ – correction taking into consideration additional counting (by the scales) of the weight of the dropping column of water into the measuring – tank in progress of the filling,

ξ_i – correction taking into consideration the hydrostatical buoyancy of the dipped inlet guide.

1. INTRODUCTION

Components of operating costs are among other things charges for domestic using of water (costs of the carrier). Therefore endeavours to the decrease of the level of charges carried by firms bear on rational using of the waters and heats and improvements of processes productions of the heat. Calculating of the consumption of energy of thermal and waters takes place basing on indications of measuring instruments are which meters of the heat and flowmeters. For the mark of the quality and the statement of the correctness of the work of flowmeters and calorimeters, attend suitable methods and manners of the measurement. The absent of the sufficiency of testing laboratories (legalization) in Poland to the makes the significant difficulty in the range of the realization of requirements of concerning qualities of in use instruments of the measurement of the flow of liquid. Expecting solution for new investigative stands of the flow of liquid on present needs would be the construction characterizing himself:

- with low capital costs of the measuring-installation,
- with low operating costs, with the high reliability,
- with the wide range of the measurement (DN 15 – DN 500),
- with the uncomplicated procedure of the measurement,
- with small dimensions in regard to the range of the measurement.

The realization of represented requirements in a single construction is difficult in view of the series of limitations of the kind technical and legal and to the makes the serious challenge for constructors of new legalization stands. From another however aspects, new legal settlements create possibilities of the development for new testing laboratories of the flow of liquid (*the Amendments of the Law about measures from the day 27 May 2004 which is obligatory from 6 July 2004*). The application of modern solutions of equipment and programmatic mensurative of the transducers makes possible the introducing of the modification to the methodics of hitherto existing ways and on the simplification of procedures of the measurement of the stream of liquid at the saving of required accuracies.

2. THE WEIGHT- METHOD OF THE MEASUREMENT OF THE FLOW

The weight-method assorts original (the accuracy 0.05–1%) methods of the measurement of the flow and is practical as the method of calibration of instruments and stands realizing different methods of the measurement of the flow.

The weight-method to the legalization of flowmeters and calorimeters one applies in two variants:

1) with the way of the statical (Fig. 1, according to PN-EN 24185:1999) weighing,
2) with the way of the dynamical (Fig. 2, according to PN-EN 24185:1999) weighing.

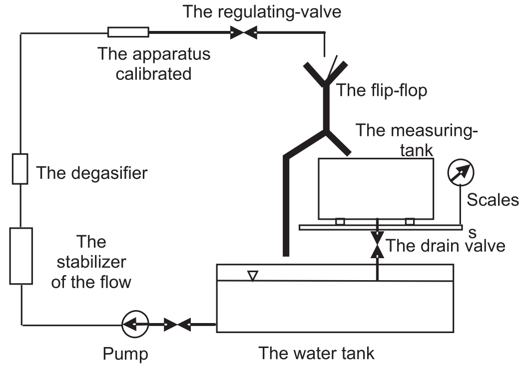

Fig. 1. The scheme of the installation to calibration of the weight-method – the statical weighing, the feed directly from the pump, according to PN-EN 24185:1999

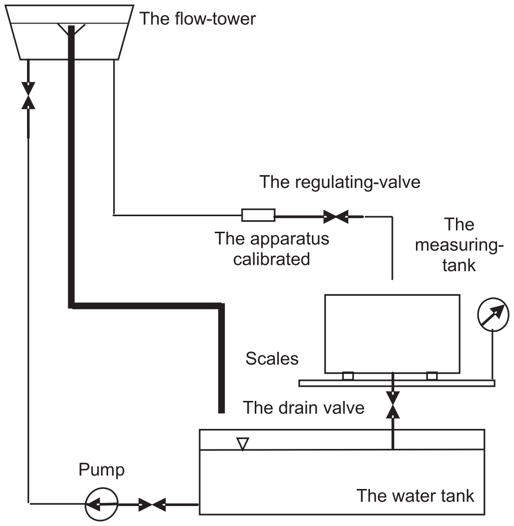

Fig. 2. The scheme of the installation to calibration of the weight-method – the dynamical weighing, the gravitational feed, according to PN-EN 24185:1999

The measurement of the flow with the weight-method makes through the measurement of the mass of liquid stored in the time interval. The difference of principle between a realization of the weight-method a statical way while a dynam-

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[1] Calculations concerning the correction of the aerostatic up thrust have been to some extent simplified by applying for the test weights an arbitrary density of the material amounting to 8000 kg/m^3. The assumption of such a value is justified by the kind of high-accuracy test weights, made of non-magnetic and stainless steel. Moreover, the assumed mean density of the air was 1.21 kg/m^3 and the temperature of the air during the control of the test weights was 20°C. These assumptions comply with OIML, according to R33.

ical way is the construction of the stand. The installation realizing the measurement of the flow a way of the statical weighing is equipped into the flip-flop of the direction of the stream (Fig. 1). The weighing of the tare and the mass the gross of the tank with water makes before and after his filling. The time of the filling measures for the moment of the directing of the stream with the flip-flop to the measuring-tank. The flip-flop of the stream starts and stops the measurement of the time.

The Main Office of Measures recommends to use to research and legalizations of flowmeters the weight-method realized with the way of the statical weighing.

The measurement of the stream of water with the dynamical way does not need the usage of the flip-flop (Fig. 2). The measurement of the mean value of the flow makes in the continuous mode during the filling of the tank through the continuous measurement of the increase of the mass of liquid and the time of the filling. Exists the possibility of measurement of transient values of the stream during investigation by means other measuring instruments installed in the installation and comparing their with the mean value, on condition that the stream of the flow during the measurement is constant.

2.1. Limitations of hitherto existing manners of measurement

Complications appear at the usage of the classical (given in PN-EN 24185:1999) weight- method in the range of large values of flows, (≥ 55 kg/s, DN 100 and larger) mainly by reason of requirements strength and constructional for both way of the measurement.

The way of the realization of the method with the manner of the dynamical weighing recommended by PN-EN 24185:1999 it bears upon technical solutions of the equipped stand into the mechanical scales. The dropping stream of liquid to the measuring-tank generates dynamic phenomena which make difficult the keeping of the required accuracy of the measurement. The destructive effect of the stream appears already at values of the flow of the order 15 kg/s [11].

The similar situation comes out at the use of the classical way of the statical weighing. The flowing stream of liquid generates related disturbances with the activity of the flip-flop of the stream.

For both cases generatings disturbances tie in with the necessity of the usage of burdensome procedures of corrections of results of the measurement of the time of the filling. Therefore one worked out modifications of this method of the measurement of the flow.

3. THE WEIGHT-METHOD WITH THE USE OF THE MODIFIED WAY OF THE DYNAMIC WEIGHING

Modifications were introduced on purpose adaptations of the weight-method for the measurement of the value of the stream of the order 200 kg/s or larger. With the assumption, which one made for during workings out of the modification of the weight-method , was the obtainment of the accuracy of the measurement of the stream required by The Main Office of Measures in Poland, to use the direct, pumper system of the feed of the installation (Fig. 3).

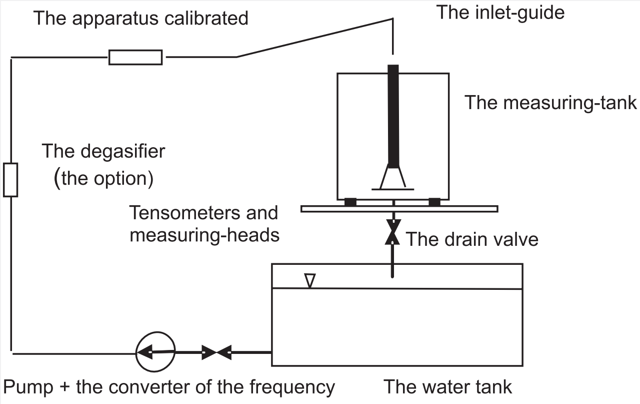

Fig. 3. The scheme of the experimental installation to calibration of the modified weight-method – the dynamical weighing, the feed directly from the pump

3.1. The way of the measurement of the method modified

The measurement of the mean value of the stream a method modified realized is automatically in the continuous mode, cyclically without necessaries of changes of the value of the stream – with the way of the dynamical weighing. The accuracy of the measurement of the flow is dependent on from the sensibility of the measuring-system of the mass on due disturbances an influence of the coming down stream to the measuring-tank. For the purpose of the elimination of disturbances of the measurement of the flow, one introduced modifications through the use of the electronic scales, joint with the programmable controller PLC. Equipped scales is into the set of digital low-pass filters of the fourth order. Scale was provided into three heads with tensometers and abilities to self-aligning on which one settled himself directly the measuring-tank. By dint of such modification the switching of the chronometer (the element of the application of the controller PLC) makes only on the way of electric impulses, without necessaries of the usage of procedures corrections of the time of the filling (necessary in hitherto existing procedures of the measurement). Consequently, the measurement of the time of the filling is independent for the measurement of the mass.

The stream of liquid coming in (without the dispersion streams) to the tank, strikes hydraulically for the bottom and causes the waving of water. For the purpose of the elimination of this undesirable phenomenon one introduced the next modification consisting in to the use of the special (author's) construction of the flow inlet-guide of the stream, reducing the negative influence of the dynamics of the stream on the accuracy of the measurement. The construction of the flow inlet-guide is mechanically isolated out of the tank and does not transfer disturbances on the scale (the independent construction). The constant stream is assured by the stabilization of the rotational speed of the feed-pump. Pump has the steep characteristics, what causes the low sensibility of the flow in relays level waters basined feeding.

4. THE METHODICS OF REALIZED DESIGN-TIME INVESTIGATION

For the purpose of examinings of the metrological properties of the experimental measuring-system of the modified weight-method for calibration, one worked out the mathematical model of the process of the measurement of the stream, to put to use the conception of the joint modelling equipment and functional of measuring-systems. Such treatment makes possible the analysis of the property metrological properties of the measuring-system before his constructing on the stage of the design to simulate the measurement.

The mathematical model of the measuring-system is a simplified form of the description of phenomena occurring in the real measuring-system. Formulating of the model is based on the mapping of recognizable properties of analyzed system, considering consequential aspects from the way of gaining over of input-magnitudes. Connected difficulties with the quality of the mapping of the function of the transformation of the measuring-system in his model, tie in with the intensity of the negative influence of disturbances on the considered measuring-system.

4.1. The model of the measuring-system of the weight-method

The construction of the model of the mathematical measuring-system of the weight- method is based on the conception of the joint modelling of the equipment and the modelling of the function of components of the measuring-system related transformed signals [1, 2]. The general form of models formulated according to proposed conception to the makes the set of three submodels:

The definitional model of the measuring-system (being with the reference model), expresses the aim of the work of the system, also the way of gaining over of results of measurement by the assumption of the error-free transformation of the magnitude measured.

The model of the real system is the setting of models of functional elements in the structure mapping the real measuring-system by the use of input and output signals. This model of the regard all proprieties of the system and technical parameters of the system.

The model of errors of the system defines the fidelity of the realization of the function of the real measuring-system with relation to of the definitional model to satiated. This model takes into consideration together all elements, both mapped as and not mapped in the model of the real system.

For the purpose of warrantings high-quality of the mapping of the definitional model in the real system by the absence of the sufficient permissive information on the formulating of the mathematical model of the system real, is possible the description of the model of errors. Accept for the simplification the description of the model in the form of the uncertainty of the measurement, we can easily imitate in it recognizable technical parameters, the structure of the system, the disturbance, the propriety of algorithms of the control and the transformation variable take into consideration with this real proprieties of designed measuring-system.

The definitional model represent following formulas:

– for the stream of the mass of liquid

$$q_m = [(m_1 - m_0)/t][1+\rho_a(\rho^{-1} - \rho_p^{-1})] \tag{1}$$

– for the stream of the volume of liquid

$$q_v = [(m_1 - m_0)/\rho t][1+\rho_a(\rho^{-1} - \rho_p^{-1})] \tag{2}$$

The extended uncertainty of the model of the real system:

$$U = k\,u_c(y) \tag{3}$$

$$u_c(y) = \left[\sum_{j=1}^{N} c_j^2 u_A^2(x_j) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} c_i c_j u_A(x_i, x_j) + \sum_{i=1}^{M} c_i^2 u_B^2(x_i)\right]^{\frac{1}{2}} \tag{4}$$

where:

$$\sum_{i=1}^{M} c_i^i u_B^2(x_i) = c_1^2 u^2(m_1) + c_2^2 u^2(m_0) + c_3^2 u^2(t) + c_4^2 u^2(\rho_a) + c_5^2 u^2(\rho) + c_6^2 u^2(\rho_p) \tag{5}$$

$$c_1 = \frac{\partial q_m}{\partial m_1} = t^{-1}[1+\rho_a(\rho^{-1} - \rho_p^{-1})] = q_m(m_1 - m_0)^{-1} \tag{6}$$

$$c_2 = \frac{\partial q_m}{\partial m_0} = -t^{-1}[1+\rho_a(\rho^{-1} - \rho_p^{-1})] = -q_m(m_1 - m_0)^{-1} \tag{7}$$

$$c_3 = \frac{\partial q_m}{\partial t} = -[(m_1 - m_0)t^{-2}]\cdot[1+\rho_a(\rho^{-1} - \rho_p^{-1})] = -q_m t^{-1} \tag{8}$$

$$c_4 = \frac{\partial q_m}{\partial \rho_a} = [(m_1 - m_0)t^{-1}](\rho^{-1} - \rho_p^{-1}) = q_m(\rho^{-1} - \rho_p^{-1})[1+\rho_a(\rho^{-1} - \rho_p^{-1})^{-1} \tag{9}$$

$$c_5 = \frac{\partial q_m}{\partial \rho} = [(m_1 - m_0)t^{-1}](-\rho_a \rho^{-2}) = -q_m(\rho_a \rho^{-2})[1+\rho_a(\rho^{-1} - \rho_p^{-1})]^{-1} \tag{10}$$

$$c_6 = \frac{\partial q_m}{\partial \rho_\pi} = [(m_1 - m_0)t^{-1}](\rho_a \rho_p^{-2}) = q_m(\rho_a \rho_p^{-2})[1+\rho_a(\rho^{-1} - \rho_p^{-1})]^{-1} \tag{11}$$

In modelled measuring-system of the weight-method tracks of the signal processing are independent; therefore one accepted that uncertainties of the type B in the model had a zero-value of the covariance. Therefore also the central element of the equation (3) one can skip. The first element of the equation (3) we skip on this stage, for the absence of real results of measurement in the phase of the design engineering.

4.2. The manner of design-time research

Design-time research with the use of the model of the uncertainty [5] consist in the description of the initial characterization of the uncertainty of the measuring-system by means the simulation of characteristicses of model inaccuracies of equipment elements of the system, in the form of the uncertainty of results of the measurement of the type B (equations from (3) to (11)). Characteristicses model uncertainties of the type B one estimates to use the method of the analysis of conditions of the existence of the source of the error, to fix the dispersion of the density of the probability of set, whence accrues the error. This analysis takes over [4, 5]: obtained earlier measuring-data, the experience and the currently accessible knowledge on of the maintenance and the propriety of in use instruments and materials, the specification of the producer plus connected uncertainties with datum of the reference with laded from the literature.

For the exemplifying of the process of the modelling of the uncertainty of the indirect measurement, one can use with the cybernetic image of the indirect measurement in the form as on the sketch. 4 (Fig. 4).

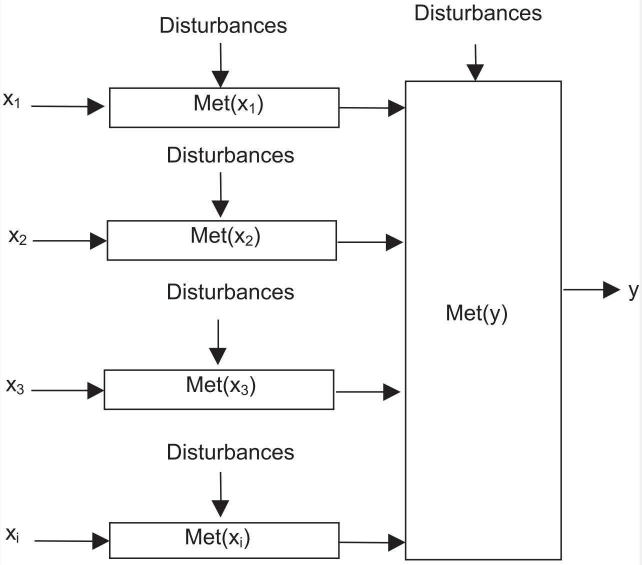

Fig. 4. The cybernetic image of the method of the measurement of the indirect magnitude in which one can change independently each from ways of the measurement of the magnitude of independent Met(x_i) [10]

This object we deleave corresponding to the method of Met(y) of the measurement of the magnitude y and to ways of Met(x_i) of the measurement individual variable x_i. An assignment of the modelling of the uncertainty of the measurement is the description of possibly requisite changes of the method necessary for the success of the final result with a possibly minimus uncertainty [10]. The process we carry on to use “test-values” of each immediate magnitude to estimate their uncertainties. This one work consists in the verification of separately individual ways of Met(x_i) on the whole of the method of Met(y). This way one can “easily” estimate and compare the influence of input magnitudes on the output. Results of the analysis with the information on of the domination of uncertainties brought in from influences systematical and accidental, in measurement of individual input magnitudes x_i, will permit to choose the most proper way of the realization of final measurement and estimations of the uncertainty [10].

4.3. The sensitivity analysis

The methodic of simulatory investigation in the phase of the design engineering with the use of the model of the uncertainty (equations (3)–(11)) of the system of the weight- -method for the measurement of the flow, allows simultaneously on the calculating of the sensibility of components of the investigated system.

The sensibility of measuring-systems defined is as the dependence between results of measurement and magnitudes measured, determinative the inclination of statical characteristics – the sensibility of the dependent variable from the independent variable. In the scalar case it is a linear approximation of this dependency, in the closing in of the accepted point by means the derivation.

In the bibliography is the other formulation of the sensibility of the system as dependences between results of measurement and with systematic errors while with parameters of systems and disturbances, defining the susceptibility on the influence of negative [1, 2, 6] factors . The seizure this refers models of systems about the complicated form, not necessarily analytic in relation to influent factors, because the possibility of their differentiation seems rather doubtful. The carrying on of simulatory research on suchlike models needs usages of the definition of the sensibility about complete increases and controlled values [1, 6].

For the description of the sensibility of the considered system of the weight-method for the evident and analytical form of the model one accepted definitions of the sensibility based on the Taylor’s series – (equations (6)–(11)).

4.4. The analysis of the uncertainty

The analysis of the uncertainty of the measurement, defined sometimes with the name of the budget of the uncertainty [11], contains the list of all sources of occurrent uncertainties during the measurement in this case fictitious (simulative) along with suitable standard-uncertainties as well as with ways of their calculation (Tab. 1). For the purpose of clarities one complies [11] the representation essential for this analysis datum in the form of the table.

For each input magnitude in the table, are:

- estimator of the input magnitude x_i (there are them measuring-magnitudes),
- connected with it the standard-uncertainty of the measurement $u(x_i)$,
- the coefficient of the sensibility c_i, (determined on the basis of (6)–(11)),
- the component of the uncertainty $u_i(y) = c_i\, u(x_i)$ (the participation in the complex standard-uncertainty $u_i(y)$),
- numerical values x_i (there are them measuring-magnitudes) along with suitable units of measure.

Table 1

The example of the budget of the uncertainty of the type B of the measuring-system by the dynamical weighing; the modelling for: $\beta = 0$ and $k = 1.38$

Symbol X_i	Estimate x_i	The standard – uncertainty $u(x_i)$ / the category of the uncertainty	The probability distribution	The coefficient of the sensibility c_i	The participation in the composite standard– uncertainty $u_i(y)$
m_1	1767 kg	0.276 kg	type “U”	0.01430 1/s	0.004 kg/s
m_0	500 kg	0.276 kg	type “U”	–0.01430 1/s	–0.004 kg/s
t	70 s	0.008 s	rectangular	–0.25885 kg/s^2	$-2.07\cdot10^{-3}$ kg/s
ρ_a	1.21 kg/m^3	0.020 kg/m^3	rectangular	0.01588 m^3/s	$3.18\cdot10^{-4}$ kg/s
ρ	998.20 kg/m^3	0.057 kg/m^3	rectangular	$-2.19801\cdot10^{-5}$ m^3/s	$-1.25\cdot10^{-6}$ kg/s
ρ_p	8000 kg/m^3	0.080 kg/m^3	rectangular	$3.42204\cdot10^{-7}$ m^3/s	$2.74\cdot10^{-8}$ kg/s
q_m	18.11 kg/s				$5.91\cdot10^{-3}$ kg/s
The extended uncertainty		$k = 1.38$			$8.15\cdot10^{-3}$ kg/s

On the basis of this analysis we can describe definitively the extended uncertainty U the equation (3). If the standard-uncertainty $u_c(y)$ related with estimator of the of the output magnitude will get definite by designers with comfortable reliability and the distribution of her we will characterize with the normal distribution then in the analysis uses standardly the coefficient of the extension $k = 2$ corresponding to the level of the confidences 95% [11].

In the situation, when one cannot accept the assumption about the normal distribution, is indispensable the taking of the information on the real probability distribution estimator's y for the purpose of definitions of the coefficient of the extension k, for level confidences 95% [11].

5. SELECTED RESULTS OF THE DESIGN-TIME INVESTIGATIONS

For the description of spurious uncertainties of results of the measurement of the stream a method modified of designed measuring-system ,one seems legitimate the acceptance of the distribution of the density of the probability of the type U, in view of occurrent vibrations of the tank at the time of his fillings.

Seeing that the amplitude of vibrations of the measuring-signal is insignificantly low comparatively with the integral constant being descended from of the weight of the tank with liquid, for the description of the standard-uncertainty $u(m_1)$ and $u(m_0)$, spurious measuring-magnitudes m_1 and m_0, one accepted the model distribution of the density of the probability which illustrates the Figure 5.

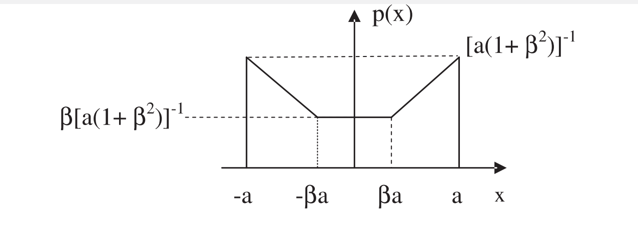

Fig. 5. The distribution of the density of the probability of the type U accepted for the modelling of standard – uncertainties $u(m_1)$ and $u(m_0)$, spurious magnitudes m_1 and m_0. (β – edging parameter of the assumed distribution of the probability)

The coefficient of the extension k for level confidences 95% and the standard – uncertainty $u(x_i)$ in this distribution are relative to the coefficient β (β – edging parameter of the assumed distribution of the probability) [11]. For the assumed probability distribution for the level confidences 95%, the coefficient of the extension k, to use the methodology recommended in [11], one defines from formula

$$k = 0.95\frac{\sqrt{6(1+\beta^2)^3}}{2\beta\sqrt{3+\beta^4}} \tag{12}$$

The standard-uncertainty $u(m_1)$ and $u(m_0)$ spurious magnitudes m_1 and m_0, for the assumed probability distribution of the type U describes the determined formula at the using [11]

$$u(x_i) = a\sqrt{\frac{3+\beta^4}{6(1+\beta^2)}} \tag{13}$$

In the analysis one considered three variants, to assume for the modelling coefficients $\beta = 0$, $\beta = 0.5$ and $\beta = 1$. Next one calculated values of the coefficient of the extension k and standard-uncertainties, for each value of the coefficient β.

In the case, when $\beta = 1$, the influence of vibrations on the accuracy of the measurement of the magnitude m_1 and m_0 one can skip. Because for the value $\beta = 1$ the probability distribution of the type U becomes transformed into the rectangular distribution. For $\beta = 0$ (represented in the Fig. 5 the distribution of the density of the probability becomes transformed into the distribution of the type V) the standard-uncertainty $u(x_i) = \frac{a}{\sqrt{2}}$ one calculated and $k = 1.38$.

For $\beta = 0.5$ and one calculated $k = 1.52$.

For $\beta = 1$ were defined $u(x_i) = \frac{a}{\sqrt{3}}$ and one calculated $k = 1.64$.

Table 2

The example of the budget of the uncertainty of the type B of the measuring-system by the dynamical weighing, the modelling for: $\beta = 0.5$ and $k = 1.52$

Symbol X_i	Estimate x_i	The standard – uncertainty $u(x_i)$/the category of the uncertainty	The probability distribution	The coefficient of the sensibility c_i	The participation in the composite standard – uncertainty $u_i(y)$
m_1	1767 kg	0.250 kg	type “U”	0.01430 1/s	$3.6 \cdot 10^{-3}$ kg/s
m_0	500 kg	0.250 kg	type “U”	–0.01430 1/s	$-3.6 \cdot 10^{-3}$ kg/s
t	70 s	0.008 s	rectangular	–0.25885 kg/s^2	$-2.07 \cdot 10^{-3}$ kg/s
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ρ_p	8000 kg/m^3	0.080 kg/m^3	rectangular	$3.42204 \cdot 10^{-7}$ m^3/s	$2.74 \cdot 10^{-8}$ kg/s
q_m	18.11 kg/s				$5.50 \cdot 10^{-3}$ kg/s
The extended uncertainty		$k = 1.52$			$8.36 \cdot 10^{-3}$ kg/s

Table 3

The example of the budget of the uncertainty of the type B of the measuring-system at the dynamical weighing; the modelling for: $\beta = 1$ and $k = 1.64$

Symbol X_i	Estimate x_i	The standard – uncertainty $u(xi)$/the category of the uncertainty	The probability distribution	The coefficient of the sensibility c_i	The participation in the composite standard – uncertainty $u_i(y)$
m_1	1767 kg	0.225 kg	type “U”	0.01430 1/s	$3.2 \cdot 10^{-3}$ kg/s
m_0	500 kg	0.225 kg	type “U”	–0.01430 1/s	$-3.2 \cdot 10^{-3}$ kg/s
t	70 s	0.008 s	rectangular	–0.25885 kg/s^2	$-2.07 \cdot 10^{-3}$ kg/s
ρ_a	1.21 kg/m^3	0.020 kg/m^3	rectangular	0.01588 m^3/s	$3.18 \cdot 10^{-4}$ kg/s
ρ	998.20 kg/m^3	0.057 kg/m^3	rectangular	$-2.19801 \cdot 10^{-5}$ m^3/s	$-1.25 \cdot 10^{-6}$ kg/s
ρ_p	8000 kg/m^3	0.080 kg/m^3	rectangular	$3.42204 \cdot 10^{-7}$ m^3/s	$2.74 \cdot 10^{-8}$ kg/s
q_m	18.11 kg/s				$4.99 \cdot 10^{-3}$ kg/s
The extended uncertainty		$k = 1.64$			$8.00 \cdot 10^{-3}$ kg/s

Table 4

The example of the budget of the uncertainty of the type B of the measuring-system by the dynamical weighing, the modelling for: $\beta = 1$ and $k = 2$

Symbol X_i	Estimate x_i	The standard – uncertainty $u(x_i)$/the category of the uncertainty	The probability distribution	The coefficient of the sensibility c_i	The participation in the composite standard – uncertainty $u_i(y)$
m_1	1767 kg	0.225, kg	type “U”	0.01430 1/s	$3.2 \cdot 10^{-3}$ kg/s
m_0	500 kg	0.225 kg	type “U”	–0.01430 1/s	$-3.2 \cdot 10^{-3}$ kg/s
t	70 s	0.008 s	rectangular	–0.25885 kg/s^2	$-2.07 \cdot 10^{-3}$ kg/s
ρ_a	1.21 kg/m^3	0.020 kg/m^3	rectangular	0.01588 m^3/s	$3.18 \cdot 10^{-4}$ kg/s
ρ	998.20 kg/m^3	0.057 kg/m^3	rectangular	$-2.19801 \cdot 10^{-5}$ m^3/s	$-1.25 \cdot 10^{-6}$ kg/s
ρ_p	8000 kg/m^3	0.080 kg/m^3	rectangular	$3.42204 \cdot 10^{-7}$ m^3/s	$2.74 \cdot 10^{-8}$ kg/s
q_m	18.11 kg/s				$4.99 \cdot 10^{-3}$ kg/s
The extended uncertainty		$k = 2$			$10.00 \cdot 10^{-3}$ kg/s

In Tables from 1 to 3 one represented budgets of the uncertainty of the type B so as this was characterized in the point 4, to use formulas from (1) to (11) and take into consideration modelled values $u(m_1)$ and $u(m_0)$ the magnitude m_1 and m_0 and model values of the coefficient k for assumed values β.

Results of the model analysis taken down in Tables 1–3, prove that the occurrence of vibrations of the tank ($\beta = 0$ and $\beta = 0.5$ appear vibrations) during spurious measurement of the magnitude m_1 and m_0, increase the standard-uncertainty $u(m_1)$ and $u(m_0)$ also the extended uncertainty „U". The growth of the interference level related with vibrations of the tank causes the reduction of the value of the coefficient k. Such situation makes designers of the considered measuring-system for the use of solutions minimalizing of the vibration of the tank in progress of the filling (modifications described in the section 3).

Above-results prove that "the arbitrary" assumption of the coefficient of the extension $k = 2$, in accordance with recommendations [11] warrants the level of the confidence better than 95%

The budget of the uncertainty for $k = 2$ are represented by the Table 4.

6. EXPERIMENTAL RESEARCH ON THE STAND FOR THE MEASUREMENT OF THE FLOW WITH THE METHOD MODIFIED

6.1. Stand tests

On purpose ascertainments or the assumed mathematical model of the measurement (with simplifications) for the analysis provides the correct description of the process of the measurement one realized experimental tests. This one tests were executed on the prototype installation of the measurement of the flow of the modified weight-method [19, 20].

Experimental research with the modified weight-method consisted in to fix of the mean value of the flow and the first-hand comparison with the indication of the electromagnetic supervisory flowmeter. During research one measured the increase of the mass $\Delta m = m_1 - m_0$ of water tanked and corresponding to this the time of the filling of the measuring-tank $t = t_1 - t_0$ as well as the stream of the volume indicated by the supervisory electromagnetic flowmeter.

Used in comparative research the supervisory electromagnetic flowmeter was legalized by the accredited laboratory which makes sure of traceability of carried on measurement to the governmental pattern, by the intermediary of the uninterrupted chain of comparisons. The comparison of results of the measurement of the stream a method modified with performance of the supervisory electromagnetic flowmeter is equivalent with a reference their to the governmental pattern (the stream of the laboratory calibrating).

6.2. Selected results of measurement

At the time of measurement one observed the occurrence of two phenomena. These phenomena appear during the filling of the tank in progress of the measurement of the stream and they are a consequence of introduced modifications. The first phenomenon then additional counting of the weight of water by the scales, proceeding from the dropping column of water which takes place during rises level waters basined. The occurrence of this phenomenon needs corrections of the mean value of the fixed stream of the mass. Therefore one introduced the correction which is dependent on exactly of constructional features of the measuring-tank used in the installation [19, 20]. The second occurrent phenomenon in the process of the measurement refers the buoyancy of the hydrostatical inlet-guide of ducked. The occurrence of the phenomenon of the buoyancy demands also corrections of the mean value of the stream. So one introduced the second correction dependent exactly of constructional features of the inlet-guide.

To take so under the attention mentioned phenomena, the real value of the stream of the mass of water one defines on the basis of equation [19, 20]

$$q_m = \frac{m_1 - m_0}{t_1 - t_0}\left(1 + \rho_a\left(\frac{1}{\rho} - \frac{1}{\rho_p}\right)\right) \cdot \left(1 - \frac{A_{\text{dropping\_ flow}}}{A_{\text{container}}}\right) - \xi_{qm} \tag{14}$$

In the Table 5 were represented selected results of measurement and their analysis. Uncertainties of the category A one estimated on in accordance with guiding principles given in [5]. Uncertainties of the category B, one defined so as in the point 4, considering coefficients of the sensibility, definite on the basis of the model of the definitional equation (1 and 2).

7. THE RESUMING

Suggested conception of the measurement of the stream with the modified weight-method, asserts minimalizing of the negative influence of dynamic actions on the measurement of the mass, to values neglected. Because results of the simulatory (design-time) research (Tab. 4 for $\beta = 1$ and $k = 2$) do not deviate significantly from the value of results of measurement on the investigative (Tab. 5, $k = 2$) stand. Further more it is possible on this principle to conclude that the assumed model of the measurement gives the correct description of phenomena occurring in the measuring-process.

Predisposes this the considered method of the measurement of the stream to research of the flow of liquid in closed pipes, for large streams of the mass, in accordance with requirements of due acts of the legal metrology.

Proposed on the article the methodics of simulatory (design-time) research makes easy the taking on of decisions on of constructional solutions of the measuring-system in the phase of the design engineering and workings out of the conception of the measurement. The approach this assures savings of human energies and material means. The modelling and the simulation of the uncertainty of the measuring-system permits to improve initial, expensive and difficult organizationally, the traditional process of the identification of the model only on the basis of results of measurement.

Table 5

The analysis of the uncertainty of the measurement of the considered measuring-system with the weighing with the dynamical way being descended from of recognizable influences systematical and accidental for estimated stream of the mass with the taking into consideration of corrections; one described in accordance with the formula (14) β = 1 and $k = 2$

Symbol X_i	Estimate x_i	The standard – uncertainty $u(xi)$/the category of the uncertainty	The probability distribution	The coefficient of the sensibility c_i	The participation in the composite standard – uncertainty $u_i(y)$
m_1	1767.000 kg	0.225 kg/B	rectangular	0.01430 1/s	$3.2 \cdot 10^{-3}$ kg/s
m_0	500.000 kg	0.225 kg /B	rectangular	–0.01430 1/s	$-3.2 \cdot 10^{-3}$ kg/s
t	70.006 s	0.008 s /B	rectangular	–0.25885 kg/s^2	$-2.07 \cdot 10^{-3}$ kg/s
ρ_a	1.210 kg/m^3	0.020 kg/m^3 /B	rectangular	0.01588 m^3/s	$3.18 \cdot 10^{-4}$ kg/s
ρ	998.200 kg/m^3	0.057 kg/m^3 /B	rectangular	$-2.19801 \cdot 10^{-5}$ m^3/s	$-1.25 \cdot 10^{-6}$ kg/s
ρ_p	8000.000 kg/m^3	0.080 kg/m^3/B	rectangular	$3.42204 \cdot 10^{-7}$ m^3/s	$2.74 \cdot 10^{-8}$ kg/s
q_m	17.420 kg/s				$4.99 \cdot 10^{-3}$ kg/s
q_m	17.420 kg/s	5.55 10^{-3} kg/s/A	normal	1	$5.55 \cdot 10^{-3}$ kg/s
$\left(1-\frac{A_{str}}{A_{zb}}\right)$	Uncertainty of the correction /B				$1.1 \cdot 10^{-3}$ kg/s
ξ_{qm}	Uncertainty of the correction /B				$4.69 \cdot 10^{-3}$ kg/s
The extended uncertainty		$k = 2$			$18 \cdot 10^{-3}$ kg/s

The modelling of the uncertainty makes possible the choice and the verification of the equipment and the measuring – apparatus also the structure of the considered system, discover possible uncertainties with which one ought to matter by the use of chosen solution already on the stage of the design engineering of the measuring-system. Performance model research, can indicate the need of the introduction of technical modifications or modifications of procedures of the measurement, for assumed criteria of the definition of errors of the measurement and the sensibility as well as disturbing elements.

On purpose further research carried on in the Institute of Power Engineering and Turbo-machinery of the Silesian Technical University is the resulting for put-upon of the modified weight-method for scientific research of the flow of liquid and the legalization of flowmeters and calorimeters as methods about the high accuracy of the measurement.

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