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The New Semi-Experimental Method for Simulation of Turbine Flow Meters Rotation in the Transitional Flow

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Abstract**—**The new semi-experimental method for simulation of the turbine flow meters rotation in the transitional flow has been developed. The method is based on the experimentally established exponential low of changing of dimensionless relative turbine gas meter rotation frequency and meter inertia time constant. For experimental evaluation of the meter time constant special facility has been developed. The facility ensures instant switching of turbine meter under test from one channel to the other channel with different flow rate and measuring the meter response. The developed method can be used for evaluation and predication of the turbine meters response and dynamic error in the transitional flow with any arbitrary law of flow rate changing. The examples of the method application are presented.

Keywords**—**Dynamic error, pulsing flow, numerical simulation, response, turbine gas meters.

I. INTRODUCTION

THE turbine gas meters are the main instruments for accounting of natural gas. They account up to 70 % of all consumed gas. These meters are also widely used as the reference meters in the standard facilities for reproducing of the volume and flow-rate units of air (gas) flow. So their good metrological condition links to saving of big money.

Because of different reasons in gas flow always there are pulsations. As a result of the turbine meters rotor inertia its rotation frequency and correspondingly meter reading always lag from the true momentary flow rate value. In the phase of flow rate decreasing the lag always bigger than in the phase of decreasing, so the average reading of the meter is always bigger than the average value of the flow-rate. This is the reason of appearing the typical for turbine meters dynamic error which is always positive.

The problem of the turbine meters dynamic errors is known for tens years. One of the first to evaluate and predicate the dynamic error was W.F.Z. Lee et al. [1]. Unfortunately according to [1] at low values of the response parameter the dynamic error becomes negative, what is impossible by nature of this error.

N. Lehmann [2] got analytical solution for transient processes in the turbine gas meters and presented dynamic error calculation results for gas flow pulsations of rectangular form, which are not occur in practice. Between of influenced parameters the parameter that defines the turbine meter rotation inertia is absent. The N. Lehmann results are involved in the PTB (Germany) normatyve document G13 [3].

The most known are the results of the K. N. Atkinson. They are obtained for sine flow rate pulsations. K. N. Atkinson results are included into ISO document [5]. Analogical results were presented by R. J. McKee [6].

All known results are obtained for rectangular or sine flow pulsations while according to investigations, for example, B Lee et al. [7] in real conditions the flow pulsation occurs by complex law.

All obtained results are based on solution of differential equation of turbine meter rotation in the transitional flow, which contains a certain number of hard-to-evaluate parameters. This is the main reason that different investigators results are fragmentary and often disagreed.

Although the problem has been known for a long time there is no exhaustive knowledge on transient processes in turbine meters simulation and meters response and dynamic errors evaluation.

The aim of this study was to develop and realize the new method of simulating the turbine gas meter behavior in pulsing flow of arbitrary pulsation law**.** The combined calculating-experimental method has been developed. The method stipulates the meter inertia time constant as the principal and only characteristic of the meter for the simulation of the meter behavior in transitional flow. The dependence for inertia time constant should be experimentally evaluated by measuring of meter response to the sharp flow rate changing from one value to another. This dependence can be used for calculating the meter response to flow changing by any law.

II. EXPERIMENTAL INVESTIGATION OF GAS METERS RESPONSE TO SHARP FLOW CHANGING

A. Experimental Facility

The special facility has been created to investigate transient processes in the turbine gas meter at sharp flow rate changing (Fig. 1). This facility ensures possibility of sharp (in shorter

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time span as in 0.1 s) switching of the tested turbine meter from the line with given initial air flow value Q_{in} into the line with other given final air flow value Q_f and to measure the turbine rotation frequency during the transient process.

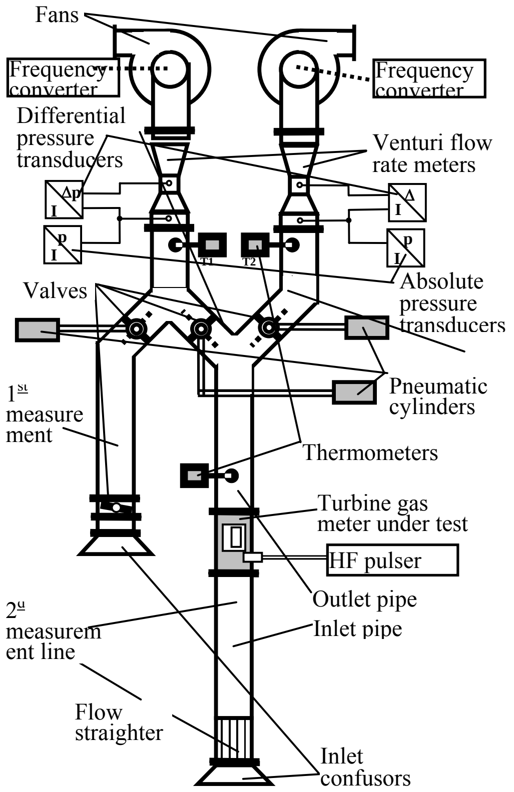

Fig. 1 Scheme of the facility for investigation of turbine gas meters response to sharp flow change

Air flows in every measurement line are produced by two fans. Instant switch of the meter under test from one measurement line to another one is carried out by three valves with pneumatic drive. Air flows rates are measured by Venturi type flow rate meters.

Vary with time of the turbine meter rotation frequency is evaluated by measuring frequency of pulses created by turbine wheel blades and using for this purpose the high frequency induction pulse sensor together with the Hewlett-Packard data acquisition and measurement system, which ensures data registration with frequency from 10 to 40 records per second.

During investigation three turbine gas meters were tested:

- the meter MZ100 of the company „Rombach“ (Germany) with plastic turbine wheel: DN100, Q = 20 - 400 m^3/h;
- the meter MZ100 of the company „Rombach“ (Germany) with metallic turbine wheel: DN100, Q = 20 - 400 m^3/h;
- the meter G650 of the company „Premagas“ (Slovakia) with metallic turbine wheel: DN150, Q = 20 - 400 m^3/h.

B. Turbine Gas Meters Response to Sharp Flow Change

Some results of investigation of the meter MZ100 with metallic turbine wheel response to sharp flow change from Q_{in} =20 - 550 m^3/h to Q_f =100, 300, 400 m^3/h and the meter „Premagas“ G650 from Q_{in} =50 - 800 m^3/h to Q_f =200, 400, 600 m3/h are presented in Fig. 2.

It can be seen that increasing of final flow rate value causes decreasing of transition process duration. It is caused by increasing of momentum of acting in transitional process aerodynamic forces with increasing of actual flow rate i.e. final one.

In all cases, whether flow rate decreases or increases, response time depends on the initial flow rate value only slightly.

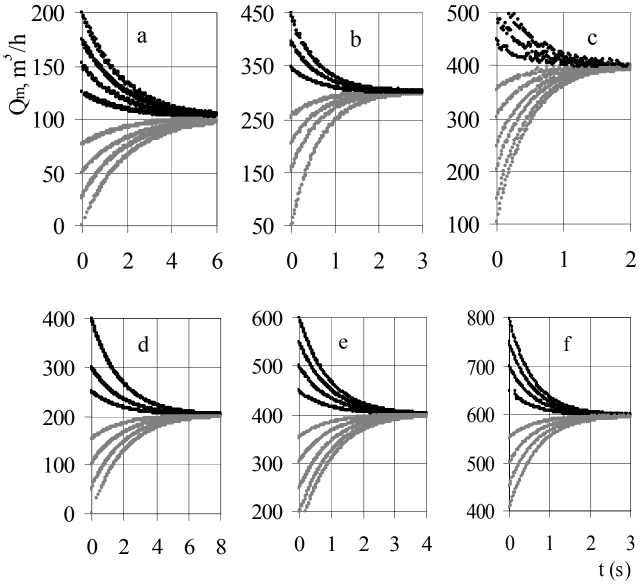

Fig. 2 Turbine gas meter response to the sharp change of flow; a, b, c - MZ100 with metallic turbine wheel, Q_f=100, 300, 400 m^3/h correspondingly; d, e, f –PREMAGAS DN150 G650, Q_f=200, 400, 600 m^3/h

Comparison of the results shows that at the same values final flow rates response duration of the meter „Premagas“ G650 is approximately two times greater as response duration of the meter MZ100 because of greater turbine size and mass and, correspondingly, greater momentum of inertia.

At Fig. 3 dependence of dimensionless excess frequency Ω of turbine gas meter MZ100 with metallic turbine wheel at Q_f = 300 m^3/h on time for all initial flow rates Q_{in} is presented as example. The initial flow rate value Q_{in} practically do not influences on the process.

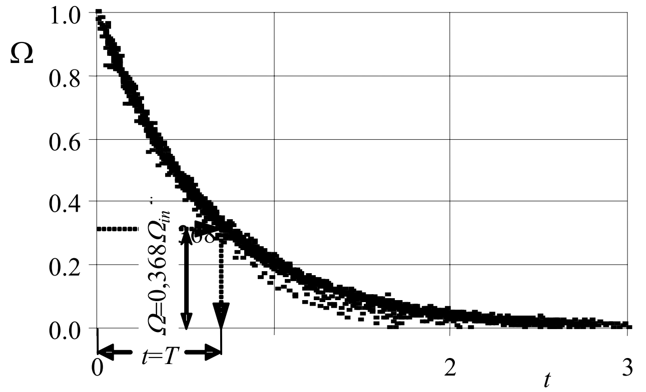

Fig. 3 Dependence of dimensionless excess frequency on time; turbine gas meter MZ100 with metallic turbine wheel, $Q_f = 300$ m^3/h

Dimensionless excess frequency Ω is determined as ratio of difference of current rotation frequency ω and final rotation frequency or corresponding to Q_f frequency ω_Q, and initial value of this difference:

$$\Omega \equiv \frac{\omega - \omega_Q}{\omega_{in} - \omega_Q}. \qquad (1)$$

C. The Turbine Meter Inertia Time Constant

The processing of the experimental results has shown that dependence $\Omega = f(t)$ in all cases of sharp flow rate changing is exponential:

$$\Omega \equiv \frac{\omega - \omega_Q}{\omega_{in} - \omega_Q} = e^{-t/T}, \qquad (2)$$

where parameter T has a meaning of turbine meter rotation inertia time constant.

The formula (2) is similar to formula for changing of dimensionless excess temperature in regular transitional process of thermoconductivity [8], and rotation inertia time constant is analogue of heat inertia time constant.

The value of the meter inertia time constant T can be evaluated from dependence dimensionless excess rotation frequency on time, as it is shown at Fig. 3. The inertia time const is equal to time during which dimensionless relative rotation frequency becomes equal to 0,368 of it initial value:

$$T = t \text{ at } \Omega = 0{,}368\Omega_{in} \qquad (3)$$

The meter inertia time const T is very important parameter. In literature for const T equation of the following type has been suggested [9]:

$$\grave{O} = \frac{C_1 J}{\rho Q}. \qquad (4)$$

Factor C_1 in equation (3) depends on viscosity of flowing through the meter gas, the meter aerodynamics and friction in the bears or on meter technical condition. This factor can be evaluated only approximately with big uncertainty. This is a big shortage of all methods for description of turbine meters transitional rotation based on equation (4) as well as equation of transitional rotation of meter rotor in traditional form. i.g. [10]

At the same the time constant T for certain turbine gas meter at fixed gas properties, first of all density and viscosity, can be determined as function of only flow rate:

$$\grave{O} = \frac{C}{\left(Q/100\right)^n}. \qquad (5)$$

Factor C and exponent n in equation (5) can be comparatively easily evaluated by above mentioned experimental method.

It should be remarked that factor C substitutes all hardly evaluated parameters that are involved into traditional equations.

As example, in Table I results of evaluating of factor C and exponent n for three tested turbine meters are cited.

TABLE I
EVALUATING OF FACTOR C AND EXPONENT N FOR TESTED TURBINE METERS

Type of a meter	Parameters C and n in equation (5)	
	C	n
PREMAGAS G650 DN150 with metallic wheel	8.616	1.006
ROMBACH MZ100 Q_{max} = 400 m^3/h with metallic wheel	4.242	0.998
ROMBACH MZ100 Q_{max} = 400 h^3/h with plastic wheel	2.289	0.956

Exponent n at flow rate for the meter in good technical condition is closed to 1. Equation (5) is valid in all working flow rate range of the turbine meter.

III. NUMERICAL SIMULATION OF THE TURBINE GAS METERS BEHAVIOR IN TRANSITIONAL FLOW

A. Peculiarities of Suggested Method

The method is based on using:

1. Experimentally ascertained exponential dependence of dimensionless excess meter rotation frequency in the transitional processes on time - equation (2).

2. Experimentally estimated meter rotation inertia time constant.

It has been assumed that any arbitrary flow rate changing in time curve can be substitute by enough closed stepped line as it is shown at Fig. 4.

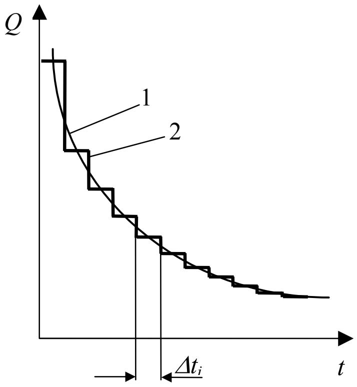

Fig. 4 Substitution of arbitrary flow rate curve by stepped line with length of step Δt_i; 1 – given flow rate curve; 2 – stepped line

If step Δt_i is small enough flow rate can be considered as constant in the limits of every step, and equation (2) can be used for every step.

Equation (2) also can be written in the differential form:

$$\frac{d\omega}{\omega - \omega_Q} = -\frac{dt}{T}. \tag{6}$$

In such form equation (2) can be used for arbitrary flow rate charging in time law. The changing of frequency ω_Q depending on flow rate pulsation should be considered.

B. Mathematical Model of the Process

Equations (2) and (4) should be added by dependence for flow rate changing in the time

$$Q = \mathrm{f}(t) \tag{7}$$

and for rotor rotation frequency ω_Q that is proportional to flow rate:

$$\omega_Q = k_Q \cdot Q \tag{8}$$

These equations should be added by border conditions. In general case this is

$$\text{at } t = 0 \rightarrow \omega = \omega_{in}. \tag{9}$$

At all practically interesting cases flow changing is periodical, i.e. flow pulsations are observed. If pulsations are regular it's advisable to use other border conditions – equality of pulsation frequency on the ends of the time segment Δt, which is equal to the pulsation period, i.e.,

$$\omega_{t=(k-1)\Delta t} = \omega_{t=k\Delta t}, \tag{10}$$

where k =1, 2, 3 ….n

With considering (7) - (8) equation (6) can be written in expanded form:

$$C\frac{d\omega}{dt} = -\omega \cdot \left(Q(t)\right)^n + k_Q \cdot \left(Q(t)\right)^{n+1}. \tag{11}$$

Equation (9) is usual differential equation of the 1 order and with border conditions (9) or (10) can be easy solved, e.g., by the Runge-Kutt method. Else more simply the equation can be solved using Microsoft Office Excel program. In this case is suitable to present results of calculation in graphic form.

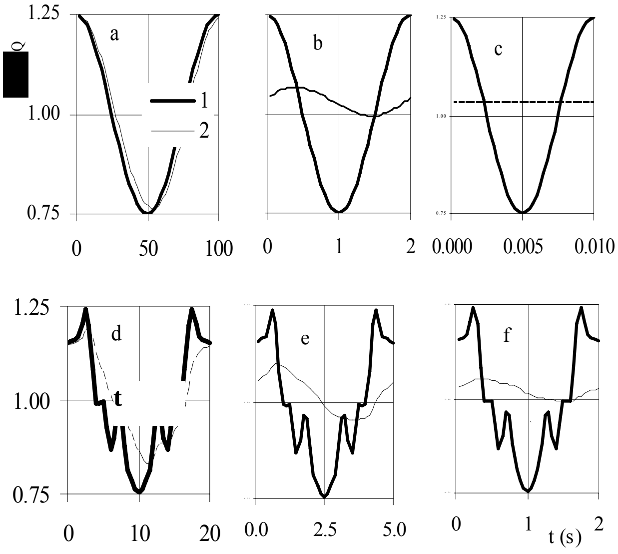

Fig. 5 Response of the gas meter MZ100 with metallic turbine wheel on flow pulsation; %, Q = 200 m^3/h; a, b, c – simple cosine law, f=0.01, 0.5, 100 Hz correspondingly; d, e, f – complex cosine law, f=0.05, 0.2, 0,5 Hz; 1 – flow rate pulsation; 2 – meter reading pulsation

Using of suggested method permits to evaluate the meter response and dynamic error as well in pulsing by any law flow.

C. Results and their Discussion

The examples of using of the method for two pulsations laws are presented at Fig. 5 for meter response and Fig. 6 for dynamic error. There was used simple cosine law:

$$\overline{Q} = 1 + \Delta\overline{Q}_r \cdot \mathrm{COS}(2\cdot\pi\cdot t\cdot f) \tag{12}$$

and complex cosine law:

$$\overline{Q} = 1 + 4/5\,\Delta\overline{Q}_r \cdot \mathrm{COS}(2\cdot\pi\cdot t\cdot f) - 1/4\,\Delta\overline{Q}_r \cdot \mathrm{COS}(8\pi\cdot t\cdot f) + 1/7\,\Delta\overline{Q}_r \cdot \mathrm{COS}(16\pi\cdot t\cdot f) - 1/12\Delta\overline{Q}_r \cdot \mathrm{COS}(20\pi\cdot t\cdot f). \tag{13}$$

With increasing of flow pulsation frequency a meter stops to response to pulsation components with small amplitude. For different flow pulsation laws at big enough pulsation frequencies a meter pulsation frequency fluctuates similarly – by cosine law. At very big flow pulsation frequencies the meter stops to response to flow rate pulsing and its rotation frequency becomes const (see Fig. 5c).

Dependence of dynamic error on flow pulsation frequency is presented at Fig. 6.

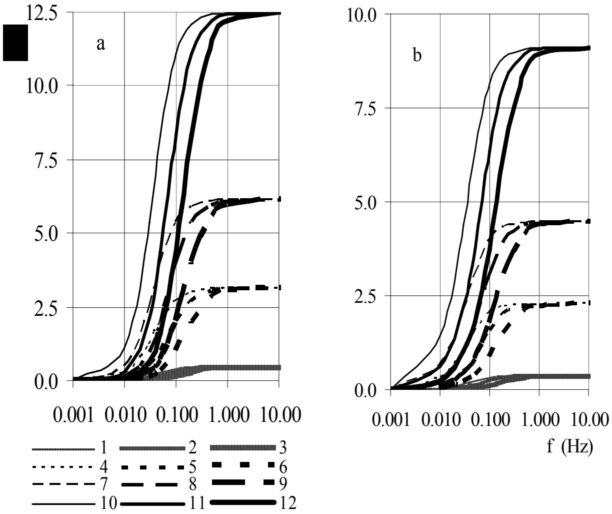

Fig. 6 Dependence of dynamic error on flow pulsation frequency, turbine gas meter MZ100 with metallic turbine wheel; a – simple cosine law; b – complex cosine law; 1, 2, 3 – relative pulsation amplitude $\Delta\overline{Q}$ =10 %, Q =100, 200, 400 m^3/h correspondingly; 4, 5, 6 – $\Delta\overline{Q}$ =25 %, Q =100, 200, 400 m^3/h; 7, 8, 9 – $\Delta\overline{Q}$ = 35 %, Q =100, 200, 400 m^3/h; 10, 11, 12 – $\Delta\overline{Q}$ =50 %, Q =100, 200, 400 m^3/h

At small frequency the meter inertia practically does not reveal, and dynamic error is very close to 0. After increasing of frequency value to 0.5 Hz the error becomes appreciable. The error increases with frequency increasing till certain limit, when because of inertia the meter stops to response to flow changing, the meter frequency is constant and dynamic error reaches its maximum value.

From calculation results it follows that dynamic error increases with increasing of amplitude pulsation by square law.

The greatest values of dynamic errors are observed for rectangular pulsation law. For cosine law the values of dynamic error are two times and for triangular law three times lesser than for rectangular law.

Calculation shows that flow pulsations of big amplitude, e.g. because of bad operation of pressure regulator can cause errors of turbine gas meters measurement up to (50-80) %.

The turbulent pulsation because of flow separation can reach the values of (3-5) % and to cause errors of measurement by reference turbine gas meters in standard facilities up to (0.05-0.1) %, what is very essential for measurement uncertainty.

The suggested method of evaluation of dynamic errors can be used not only for turbine gas meters but for water meters as well. Because of significantly bigger density the transitional region of dynamic errors curve in this case shifts to the region of bigger frequencies.

The calculation results are in good agreement with available data of other researchers, when comparison is possible, for example with results [2].

IV. CONCLUSION

1. The turbine gas meters response to sharp flow rate changing has been investigated experimentally. For this purpose new method has been suggested and experimental facility has been developed.

2. Exponential dependence of dimensionless excess meter rotation frequency on time is ascertained experimentally.

3. Conception of time constant of a meter rotation inertia has been used. The time constant can be relatively easy estimated experimentally. It substitutes all influent and hardly evaluating parameters.

4. The new approach for evaluation of turbine gas meters response to flow pulsations and for calculation dynamic error is suggested. It is based on using conception of time constant of a meter rotation inertia.

5. The method of numerical simulation of behavior of turbine gas meters in transitional flow is developed. The method permits to evaluate turbine meter response and dynamic error at flow pulsation of any law, frequency and amplitude.

6. The method is applicable not only to turbine gas meters but to water turbine meters as well.

NOMENCLATURE

J –moment of inertia of rotating parts of turbine meter ($kg \cdot m^2$);
Q – flow rate (m^3/h);
T –time constant of inertia (s);
t – time (s);
f - flow pulsation frequency (Hz);
ρ – density (kg/m^3);
k_Q – flow rate factor ($Hz/(m^3/h)$).

GREEK SYMBOLS

ρ - air density, kg/m^3;
ω - rotation frequency (Hz);
$\Omega \equiv (\omega - \omega_Q)/(\omega_{in} - \omega_Q)$ - dimensionless excess rotation frequency;
$\Delta\overline{Q}$ - relative amplitude of pulsation;
Δt_0 – pulsation period (s);
Δt_i – calculation step in time (s).

SUBSCRIPTS

av – average;
f - final;
in - initial;
m – meter;
max – maximum;
min – minimum;
r - rated.

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