ANALYSIS OF EXPLOITATION AND METROLOGICAL PROPERTIES OF A WAVE THERMOANEMOMETER SYSTEM

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Abstract: In the paper the functioning of a wave thermoanemometer with a thermoresistive sensor is presented. Three constructional variants of the sensor are described and a computer-aided system of wave thermoanemometer (WTS) is presented. Besides, exploitation properties and metrological characteristics of WTS designed and constructed by the authors are discussed. The relevant mathematical formulae are also presented.

1 INTRODUCTION

The phenomena involving the flow of a medium are very common. To name just a few examples, let us mention meteorological processes, industrial and community sewage disposal, emission of exhaust gas to the atmosphere, etc. Because of that ubiquity of flow phenomena and their significant influence on technological processes it is necessary to develop appropriate methodology and equipment for their examination. The most important flow parameters are flow velocity and temperature. Wave thermoanemometers measure the time it takes for a wave of thermal markers to pass a section of known length (Fig.1) between sensors (detectors) in a measuring converter immersed in the examined medium (gas). The wave of thermal markers flows in the medium. Section Δl is a constructional constant of the converter and the measurement of the fluid velocity is based on determining the time of passing a thermal wave flowing in the medium, according to the formula:

$$W_G = \frac{\Delta l}{\Delta t} \left[\frac{m}{s}\right] \tag{1}$$

As it follows from the functioning principle of STF presented above, the information on the velocity of the flowing gas is coded in a series (wave) of thermal impulses, flowing together with the medium.

2 CONSTRUCTIONAL VERSIONS OF WTS

The pivotal part of the WTS is a thermoresistive converter (sensor). The three constructional variants of the converter are presented in Fig.1. The variants are the following: one channel and two elements, one channel and three elements, and two channels and four elements.

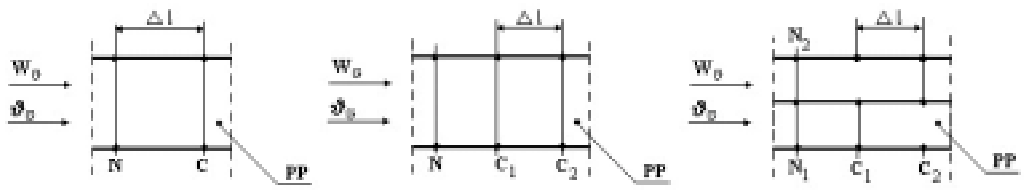

Fig. 1. Constructional variants of the thermoresistive sensor of WTS

The above described sensor must meet certain requirements – it has to be of small size, it cannot interfere with the flow field, its inertia should be small. In view of these requirements the value of parameter Δl becomes crucial. From the standpoint of accuracy of the measurements the value of this parameter should be sufficiently high, as it directly determines the value of the measured time Δt. In practice, the values ranging from a few milimeters to a few meters are encountered. However, the value of Δl is usually assumed at the level of several milimeters, as a compromise among all the criteria mentioned above. The three constructional variants of the thermoresistive sensor are the basis for three corresponding measuring systems of the WTS. The temperature measurement does not depend on the variant of the sensor, since only one element of the sensor is involved in measuring temperature as a resistive temperature sensor.

On the basis of one sensor variant (Fig. 1a) the measuring system of the WTS presented in Fig. 2 was developed.

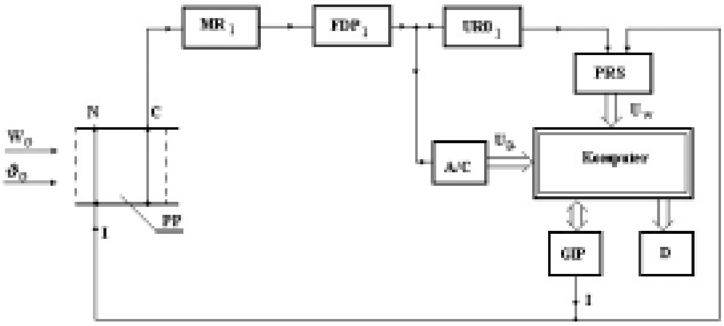

Fig. 2. WTS with a one-channel, two-element sensor

Rectangular current impulses are changed in the sending element N of converter PP into corresponding thermal markers in the flowing medium (e.g. gas). The markers hit the receiving element – detector C on the way. The measurement of time interval Δt from generating thermal markers by sender N to their detection by detector C is the basis for determining the flow velocity of the medium, according to Eqn. 1.

The construction of the sensor and the whole of the system are simple. The disadvantage is that the wire of sender N operates by much higher current than the detector wire, which may cause measurement errors resulting from the thermal dilatation.

The variant of the thermoanemometric sensor presented in fig. 1b is employed in another version of WTS, presented in Fig. 3.

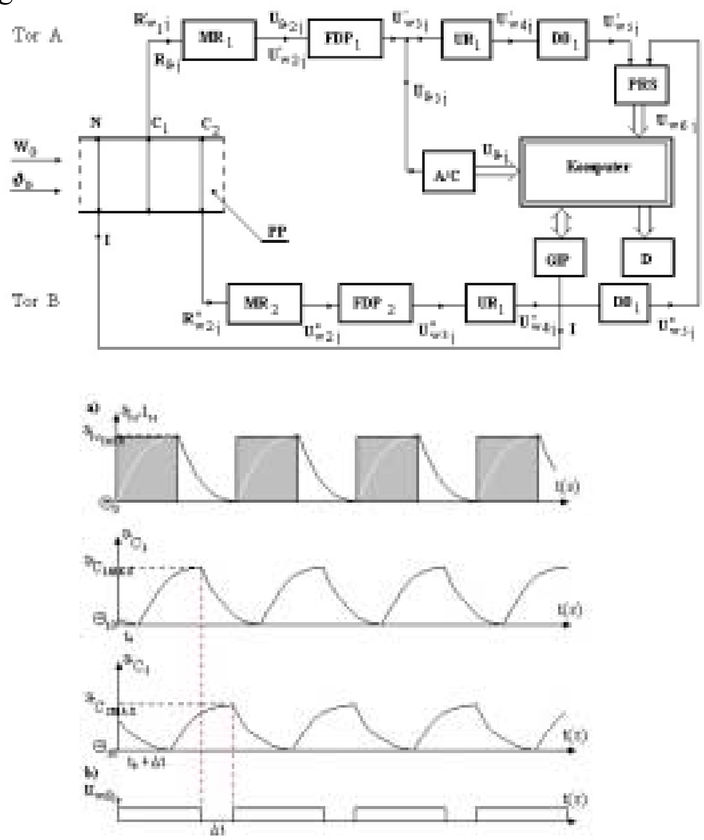

Fig. 3. WTS with a one-channel, three-element sensor

The measurement of gas velocity involves all the subsystems of WTS except the A/D converter. The parameters of the flowing medium, its flow velocity W_G and temperature ϑ_G. influence the thermoresistive elements of the sensor. The sensor is a parametric conductor, so it responds by changing the resistance of elements C_1 and C_2, which induce respective voltage signals U_W and U_ϑ. at the diagonal of measuring bridges MR_1 and MR_2. In the subsequent subsystems rectangular impulses are formed, which are directed to the computer for further processing and determining the flow velocity. The configuration of this system is slightly more complex, it is however free from errors resulting from thermal dilatation of elements C_1 and C_2.

The third variant of WTS developed by the authors is presented in Fig 4. This system is based on the thermoresistive converter as shown in Fig. 1c.

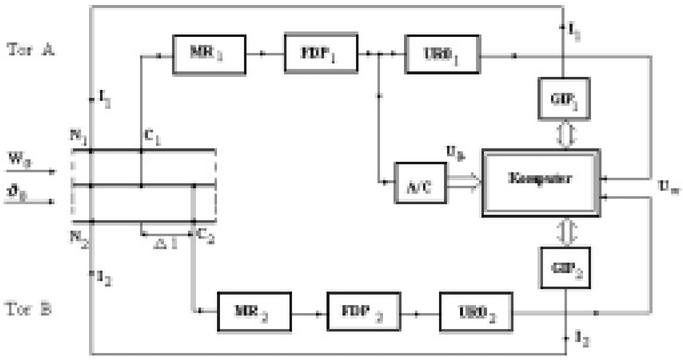

Fig. 4. WTS with a two-channel, four-element sensor

Flow velocity of the examined gas is determined from Eqn. 1, on the basis of the measured delay in generating markers by N_1 and N_2 and the known value of Δl. The presented system displays high accuracy and can be considered a zero measuring system.

3 MEASURING EQUATIONS – METROLOGICAL PROPERTIES

The analysis of the metrological properties of WTS is based on the system presented in Fig. 3. The channel of measurement of gas flow velocity W_G consists of two mating parallel lanes. The transformation of signals in the lanes from input sensors C_1 C_2, being active elements of unbalanced Wheatstone bridges, to the output proceeds in the following manner:

$$\left.\begin{array}{l} I \; - \; W_{Gj} \rightarrow R'_{W1j} \rightarrow U'_{W1j} \rightarrow U'_{W2j} \rightarrow U'_{W3j} \rightarrow U'_{W4j} \rightarrow U'_{W5j} \\ II \; - W_{Gj} \rightarrow R''_{W2j} \rightarrow U''_{W1j} \rightarrow U''_{W2j} \rightarrow U''_{W3j} \rightarrow U''_{W4j} \rightarrow U''_{W5j} \end{array}\right\} \rightarrow$$

$$U_{W6j} \rightarrow \left[Z\left[U_{W6j}\right]^{h_p}_{\Delta_k t_W} \left[m_{WG}\right]_{\Delta_k m} \right]^{h_p}_{\Delta_k W_G} \tag{2}$$

Then, in a similar way measuring equations [1] were formulated at the output of each subsystem. The equations were used for subsequent transformations of formula (2).

The above mentioned transformations led to the formula being a mathematical model of the measuring channel of gas flow velocity in WTS. The formula is the following:

$$W^*_{Gj}(t) = \left[\frac{\Delta_k t_{WZ} \cdot U_{W6m} \cdot n \cdot \Delta l}{t_l \left[Z\left[U_{W6m} \sum_{k=1}^{n} \left[1\left(t - t_k^{'n}\right) - 1\left(t - t^{'n}{}_k - \Delta t^n\right)\right] \right]_{\Delta_k t} \right]} \right]^{h_p}_{\Delta_k W_G} \tag{3}$$

Then, the necessary dependence defining the structure of errors in the considered measuring channel for gas flow velocity was formulated:

$$\Delta W_{Gj}^{*} = W_{Gj}^{*} - W_{Gj} = \Delta_{\Delta l} W_{Gj}^{*} + \Delta_{f_{WZ}} W_{Gj}^{*} + \Delta_{m} W_{Gj}^{*} + \Delta_{\Delta t} W_{Gj}^{*} + \Delta_{l_i} W_{Gj}^{*} + \Delta_{n} W_{Gj}^{*} \tag{4}$$

For defining particular components of the measuring error the following algorithms were applied:

I – practical (realistic) algorithm
$$W_{Gj}^{*}(t) = \left[\frac{\left[\dfrac{\Delta_k t_{WZ} \cdot U_{W6} m \cdot n \cdot \Delta l}{t_1} \right]_{\Delta_k m_W}}{Z\left[U_{W6} m \sum_{k=1}^{n} \left[1\left(t - t_k^n\right) - 1\left(t - t_k^n - \Delta t^n\right) \right] \right]_{\Delta_k t}} \right]_{\Delta_k W_G}^{h_p} \tag{5}$$

II – ideal (hypothethical) algorithm
$$W_{Gj}(t) = \left[\frac{\left[\dfrac{\Delta_k t_{WZ} \cdot U_{W6} m \cdot n \cdot \Delta l}{t_1} \right]_{0}}{Z\left[U_{W6} m \sum_{k=1}^{n} \left[1\left(t - t_k\right) - 1\left(t - t_k - \Delta t\right) \right] \right]_{0}} \right]_{0} \tag{6}$$

where: $t_k = t_0 + t_i + T(k-1)$: $t_i = 1, 2, ..., n$; $k = 5$

On the basis of these algorithms and equations, using specialized software MICRO – CAP II for PC extensive simulation experiments were conducted. The results indicate that from among the six components of errors, only three may significantly influence the results of measurements by means of WTS, namely: constructional component $\Delta_{\Delta l}W^*_{Gj}$ (0,13%), bistable multivibrator PRS component $\Delta_{\Delta t}W^*_{Gj}$ (0,07%), and discretization component $\Delta_m W^*_{Gj}$ (0,3%). The obtained results confirm the high accuracy of measurements by means of WTS.

4 CONCLUSIONS

- The idea of using time as an absolute value is a new development in the field of wave thermoanemometry.
- The process of measuring the parameters of gas by means of a PC is fully automatic and provides tools for immediate analysis of the components of measurement error.
- Basing the functioning principle of WTS on time measurement eliminates a number of flaws, such as the influence of sedimentation on the thermoresistive elements of the converter, the necessity of isothermal flow, and the extensometer effect.

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