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A CONSTANT-TEMPERATURE ANEMOMETER (CTA) WITH A MEANS OF ELIMINATING THE EFFECTS OF CABLE RESISTANCE ON THE PROBE OVERHEAT RATIO

ANEMOMETR STAŁOTEMPERATUROWY Z ELIMINACJĄ WPŁYWU REZYSTANCJI KABLA NA WSPÓŁCZYNNIK NAGRZANIA CZUJNIKA POMIAROWEGO

Measurements of flow velocity are an important step in the control of the air ventilation conditions in mines and ventilation processes. As metrological conditions prevailing in such situations are very specific and measurements may serve different purposes, several methods of gas flow velocity me(asurements have been developed to meet the needs of the mining sector. This paper examines the possible applications of hot wire anemometry to obtain measurements of velocity fields in fast--changing gas flows. The suggested solution of a CTA may be applied both in laboratory tests and in flow measurements in mines. The major advantage of the device is that the effects of cable resistance on the wire overheating ratio are wholly eliminated. The measuring sensor may be used in places where the distance between the sensor and the measuring apparatus is considerable and when cable resistance may vary due to ambient temperature variations.

A classical configuration for the operation of a hot-wire anemometer is the constant-temperature bridge circuit, where the resistance of the sensor-supplying cable affects the overheating ratio. This may lead to measurement errors. In order to eliminate those shortcomings, a new CTA circuit for supplying the hot wire anemometer was developed, which permits four-point measurements of the sensor resistance. The effects of cables and junction resistances on the wire overheating ratio are thus eliminated. The dynamic parameters are similar to those of the typical bridge circuit. In several metrological applications this circuit may prove to be an excellent alternative to traditional solutions. The paper examines the structure and the operating principles of the new circuit, presenting also the results of modelling and experimental tests.

Key words: flow velocity measurements, hot-wire anemometer, constant-temperature circuit, cable resistance compensation

Obszarem zainteresowań Pracowni Metrologii Przepływów Instytutu Mechaniki Górotworu PAN są metody pomiaru prędkości przepływu gazów ze szczególnym uwzględnieniem metod przydatnych w górnictwie. Pomiary prędkości przepływu stanowią ważny element badania stanu i przebiegu procesu

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wentylacji kopalń. Dla zapewnienia efektywnego przewietrzania wyrobisk kopalnianych konieczne jest ciągłe pozyskiwanie informacji o wartości parametrów wentylacyjnych w wybranych punktach kopalni. Sprawność i niezawodność systemu pomiarowego sieci wentylacyjnej wpływa na przebieg procesu eksploatacji złoża i bezpieczeństwo pracy w kopalni.

Ze względu na specyficzne warunki metrologiczne oraz zróżnicowanie celu opracowano dla potrzeb górnictwa szereg metod pomiaru prędkości przepływu gazu. W pracy tej poddano analizie problem wykorzystania metody termoanemometrycznej do pomiaru pól prędkości w szybkozmiennych przepływach gazu. Prezentowane rozwiązanie anemometru stałotemperaturowego może znaleźć zastosowanie zarówno w badaniach laboratoryjnych, jak i w kopalnianych pomiarach wentylacyjnych. Zaletą prezentowanego układu jest całkowita eliminacja wpływu rezystancji kabla na współczynnik nagrzania czujnika pomiarowego. Przeznaczony jest on więc głównie do prowadzenia pomiarów w warunkach znacznego oddalenia czujników od aparatury pomiarowej oraz w pomiarach, w których rezystancja kabla zasilającego czujniki może zmieniać się ze względu na znaczne zmiany temperatury otoczenia. Układ posiada również bardzo dobre parametry metrologiczne w zakresie małych współczynników nagrzania czujnika oraz przy pomiarach małych prędkości przepływu powietrza.

Typowym układem pracy czujnika anemometrycznego z gorącym drutem jest układ stałotemperaturowy. Posiada on bardzo dobre właściwości zarówno statyczne, jak i dynamiczne. Jest to układ regulacji automatycznej, zasilający czujnik takim prądem, aby średnia temperatura włókna utrzymywana była na zadanym poziomie. Temperatura ta jest stała niezależnie od zewnętrznych warunków wymiany ciepła. W układzie stałotemperaturowym czujnik umieszczony jest w niezrównoważonym mostku rezystancyjnym. Zadana temperatura czujnika jest uzyskiwana po zrównoważeniu mostka przez zamknięcie pętli sprzężenia zwrotnego. Prąd czujnika jest funkcją prędkości przepływu i innych parametrów wymiany ciepła. Utrzymanie zadanego poziomu współczynnika nagrzania czujnika jest istotnym warunkiem dokładności pomiarów.

Mostkowy układ stałotemperaturowy jest podstawowym układem stosowanym obecnie do zasilania czujnika anemometrycznego z gorącym drutem. W tym klasycznym układzie czujnik pomiarowy zasilany jest kablem dwuprzewodowym. Wartość rezystancji kabla ma wpływ na poziom współczynnika nagrzania czujnika. Precyzyjne pomiary wymagają więc kompensacji rezystancji kabla. Kompensacja realizowana jest poprzez pomiar rezystancji kabla po zwarciu złącza czujnika. Rezystancja kabla uwzględniana jest w mostku przy zadawaniu współczynnika nagrzania czujnika. Kompensacja taka jest jednak niewystarczająca w przypadku zmian rezystancji kabla wywołanych zmianą temperatury otoczenia podczas procesu pomiarowego. Współczesna literatura anemometryczna nie zawiera opisu metody automatycznej kompensacji rezystancji kabla w mostkowym układzie stałotemperaturowym. Szczególnie przy małym stosunku rezystancji czujnika do rezystancji kabla błędy pomiarowe mogą być tu znaczące.

Aby wyeliminować te błędy opracowano stałotemperaturowy układ zasilania czujnika anemometrycznego z czteropunktowym pomiarem jego rezystancji. Jest to oryginalne rozwiązanie układu stałotemperaturowego nie zawierające klasycznego mostka rezystancyjnego. Uzyskano całkowitą eliminację wpływu rezystancji kabla i złącza na współczynnik nagrzania czujnika pomiarowego. Nie jest więc wymagana kompensacja rezystancji kabla. Układ dzięki swoim zaletom może znaleźć zastosowanie w precyzyjnych pomiarach anemometrycznych, szczególnie przy małej rezystancji czujnika, małym współczynniku nagrzania i długim kablu zasilającym czujnik w warunkach zmiany temperatury otoczenia kabla.

W opracowanym układzie współczynnik nagrzania czujnika zadawany jest poprzez zmianę wzmocnienia w torze sygnałowym, a nie jak w układzie klasycznym poprzez zmianę parametrów mostka. Pozwala to na zadawanie współczynnika nagrzania czujnika zewnętrznym sygnałem poprzez wprowadzenie do układu elementu o zmiennym wzmocnieniu, takiego jak mnożący przetwornik cyfrowo-analogowy, mnożarka analogowa czy sterowany wzmacniacz.

W wielu zagadnieniach metrologicznych układ może stanowić alternatywę dla klasycznego układu mostkowego. W artykule omówiono strukturę i podstawy działania układu oraz przedstawiono wyniki badań modelowych i eksperymentalnych.

Słowa kluczowe: pomiary prędkości przepływu, termoanemometr, układ stałotemperaturowy, kompensacja rezystancji kabla

1. Introduction

One of the major research areas in the Laboratory of Flow Metrology in the Strata Mechanics Research Institute in Kraków is the measurement of gas flow velocities, with the main focus being on methods applicable in mines. Measurements of flow velocity form a major component in the control of air ventilation conditions in mines and ventilation processes. In order to provide effective air movement in the mine headings, it is necessary to get on-line information about the main ventilation parameters at selected points. The efficiency and reliability of the measurement systems incorporated in the ventilation network have an important influence on mining processes and work safety (Roszczynialski et al. 1992).

As prevailing metrological conditions in mines are very specific and the measurements may serve different purposes, several methods of gas flow velocity measurements have been developed to meet the needs of the mining sector. This paper examines the possible applications of hot-wire anemometry to measurements of velocity fields in fast-changing gas flows. Suggested solution of a CTA may be applied in both in laboratory tests and in measurements in mines. A major advantage of the device is that the effects of cable resistance on the wire overheating ratio are wholly eliminated. The measuring sensor may be used in places where the distance between the sensor and the measuring apparatus is considerable and when cable resistance may vary due to variations of the ambient temperature. The circuit has excellent metrological parameters over the range of small values of overheating ratio and in measurements of slow flows.

In most traditional solutions hot-wire anemometers operate in a constant-temperature configuration, as CTA circuits have favourable static and dynamic features. The circuit provides for automatic regulation; the sensor is supplied with precisely controlled current such that the average wire temperature is kept on a preset level. This temperature remains constant regardless of the external conditions for heat transfer. In CTA configurations the sensor is connected into an unbalanced resistance bridge. The preset temperature is achieved when the feedback loop is closed and bridge balanced. The sensor current is the function of flow velocity and other heat transfer parameters. Maintaining the preset overheating is required to ensure the measurement accuracy.

CTA bridge circuits are commonly used to supply hot-wire anemometric sensors (Sandborn 1972; Perry 1982; Lomas 1986). In this classical configuration the measuring sensor is supplied through a twin-wire cable. Cable resistance affects the sensor overheating levels, therefore high-precision measurements would require cable resistance compensation. Compensation is achieved through measurements of cable resistance after the sensor junction is shorted (Bruun 1995). Cable resistance in the bridge circuit has to be taken into account when the sensor overheating ratio is predetermined. However, such compensation might prove inadequate in the case of resistance changes due to variations of ambient temperature in the course of measurements. It seems that a method for automatic compensation for cable resistance in a CTA bridge circuit is still not available in the literature on the subject. When the ratio of sensor resistance to the cable resistance is low, the measurement errors may be considerable.

In order to eliminate those shortcomings, a new CTA circuit for supplying the hot-wire anemometer was created, which allows four-point measurements of the sensor resistance (Cierniak et al. 1992). It is a novel CTA configuration, without a classical bridge. The effects of cable and junction resistance on the sensor overheating are thus eliminated. Therefore, compensation for cable resistance is no longer required. Because of its obvious advantages, the circuit permits high-precision measurements in conditions of low sensor resistance, at low overheating ratio ranges and when the cables are long and where the ambient temperature might change.

The overheat ratio in the new circuit is set by controlling the amplification gain in the measuring circuit instead of changing the bridge parameters, as in most conventional systems. Accordingly, the overheating ratio can be set with an external signal through the incorporation of a gain-control element, such as an multiplying digital-analogue converter, a multiplying unit or a controlled amplifier.

In many metrological applications this circuit may prove an excellent alternative to the classical bridge configuration. The paper examines the structure and the operating principles of the new circuit, presenting also the results of modelling and experimental tests.

2. Circuit structure

The sensor current and voltage leads are separated, thus the effects of sensor cable resistance on the static characteristics of the sensor can be eliminated. This requires a constant-temperature circuit providing for resistance measurements at four-points. The measuring circuit is shown in Fig. 1. It is an original solution of a CTA circuit without a resistance bridge.

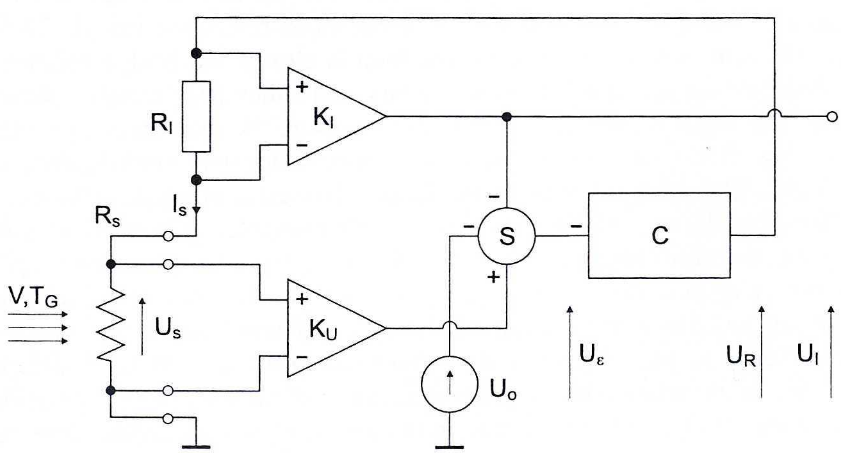

Fig. 1. Structure of the measuring circuit

Rys. 1. Struktura układu pomiarowego

The sensor R_S with separate current and voltage leads acts as the measuring element. The sensor is placed in a medium having a temperature T_G, and a flow--velocity V. The voltage across the resistor R_S is amplified in a differential amplifier with gain K_U while the voltage proportional to the sensor current in the resistor R_I is amplified in a differential amplifier K_I. Output signals from the two amplifiers are compared at the summation node S; the error signal from the node passes to the controller C, which generates such voltage U_R supplying the sensor R_S that the error voltage U_ε is reduced to zero. Assuming that the offset voltage U_0 is nearing zero, sensor resistance in the steady state remains at a constant, predetermined level, in accordance with the formula:

$$R_S = R_I \frac{K_I}{K_U} \tag{1}$$

The overheat ratio depends on amplification gains K_U, K_I and the resistance R_I. It is independent of the resistance of sensor cables and junctions. This is the major advantage of the circuit is comparison to conventional solutions.

The output signal from this circuit is the voltage proportional to the sensor current:

$$U_I = K_I R_I I_S \tag{2}$$

The new circuit does not have a resistance bridge, instead it has two differential amplifiers which are noise sources, however they are vital components of the total amplification in the feedback loop. The controller gain will be smaller than in bridge circuits. Besides, noises from the two amplifiers are partly compensated in the summation node S. The circuit does not have a resistance bridge, which would be another noise source. In bridge circuits, depending on the actual resistances values, the bridge is the major source of noise. Precise comparison between the noises generated by these two circuits will be possible only in real measurement systems.

As the main field of CTA applications are dynamic measurements, it is necessary to determine the dynamic parameters of the measurements circuits by way of model tests and experimental studies.

3. Model tests

Development of a mathematical model of the measurement circuit allows the system operation to be analysed as well as for simulation and optimisation. Also, static and dynamic parameters can be determined. The model is based on the structure of the measurement circuit shown in Fig. 1. The circuit has three basic components: an anemometric sensor, a comparator circuit and a controller. The mathematical model is based on equations describing the individual circuit components.

3.1. Model of the measurement circuit

The relationship between the wire resistance and temperature in anemometric sensors is assumed to be linear:

$$R_S = R_{S0}\left(1 + \alpha_S (T_S - T_0)\right) \tag{3}$$

where:

R_S — sensor resistance at temperature T_S,
R_{S0} — sensor resistance at the reference temperature T_0,
α_S — temperature coefficient of wire resistance at the reference temperature.

The sensor model is considered in its standard version (Ligęza 1996):

$$I_S^2 R_S = (A_S + B_S V^{n_S})(R_S - R_{SG}) + C_S \frac{dR_S}{dt} \tag{4}$$

where:

I_S — the sensor current,
R_S — resistance of the hot sensor,
V — flow velocity,
R_{SG} — sensor resistance at the temperature of the medium,
A_S, B_S, n_S, c_S — model parameters,
t — time.

Sensor resistance is compared with the preset value in the comparator circuit, which also generates the error signal to the controller. The error signal is described by an equation providing the relationship between the error voltage U_e from the summation point S and the voltage U_R. Assuming the static model of differential amplifiers K_U and K_I in the circuit shown in Fig. 1 produces:

$$U_\varepsilon = \frac{U_R}{R_S - R_1}(K_U R_S - K_I R_I) - U_0 \tag{5}$$

The last component of the measurement circuit in Fig. 1. is the controller C. Its description depends on the type and structure which have to be determined first. The analysed controller is a proportional-integrating controller, with a zero static error of regulation. The controller is composed of a real operational amplifier modelled with the inertial model of the first order. The equivalent circuit of the controller C is presented in Fig. 2, where the scheme of the real operational amplifier is plotted in a broken line. It is composed of an ideal operational amplifier A and the elements of the inertial circuit. Input resistance of the amplifier is R_A, amplifier gain equals k_A and the time constant for the applied inertial model will be:

$$\tau_A = k_A R_A C_A \tag{6}$$

The real operational amplifier, together with all external components, makes up a typical proportional-integrating controller circuit. The gain of the controller's proportional component is k_C and the time constant of the integrator is given by the formula:

$$\tau_C = k_C R_C C_C \tag{7}$$

The analysis of the equivalent circuit of a controller in Fig. 2 yields the following system of equations:

$$k_E \tau_C \frac{dU_C}{dt} = (1 - k_E) U_C + (k_E - 1) U_R - k_C U_\varepsilon \tag{8}$$

$$k_E \tau_C \frac{dU_R}{dt} = k_A U_C - (k_A + k_E) U_R - k_A k_C U_\varepsilon \tag{9}$$

where:

$$k_E = \frac{k_C R_C + k_C R_A + R_A}{R_A} \tag{10}$$

is an equivalent parameter introduced here for the sake of simplification. These equations and the initial conditions for the voltages U_C and U_R constitute the mathematical model of a real proportional-integrating controller PI, shown in Fig. 2.

These relationships lead to the model of the measurement circuit presented in Fig. 1. The variables of state are voltages U_C and U_R of the controller C and the resistance of the anemometric sensor R_S. Considering equation (4) which describes the sensor and equation (5) describing the comparing circuit, as well as equations (8) and (9) describing the controller C and eliminating U_e, we obtain a system of equations describing the measurement circuit rewritten as:

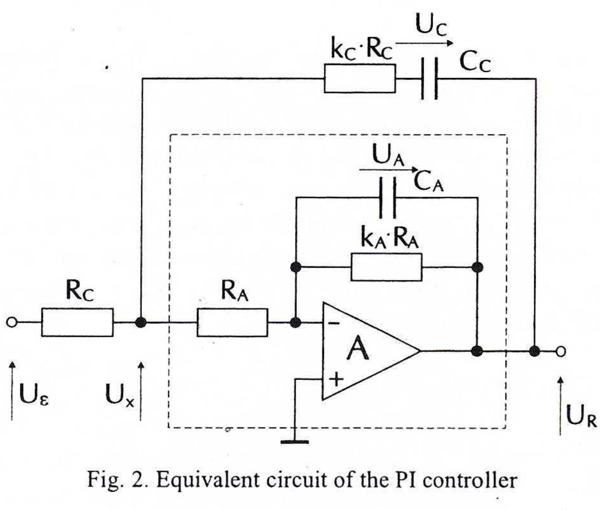

Fig. 2. Equivalent circuit of the PI controller

Rys. 2. Schemat zastępczy regulatora PI

$$\frac{dU_C}{dt} = \frac{1}{k_E \tau_C} \left\{ (1-k_E) U_C + \left[k_E - k_C \left(\frac{K_U R_S - K_I R_I}{R_S + R_I} \right) - 1 \right] U_R + k_C U_0 \right\} \tag{11}$$

$$\frac{dU_R}{dt} = \frac{1}{k_E \tau_A} \left\{ k_A U_C + \left[k_E + k_A k_C \left(\frac{K_U R_S - K_I R_I}{R_S + R_I} \right) + k_A \right] U_R + k_A k_C U_0 \right\} \tag{12}$$

$$\frac{dR_S}{dt} = \frac{1}{c_S} \left[\frac{U_R^2 R_R}{(R_S + R_I)^2} - (A_S + B_S V^{N_S})(R_S - R_{SG}) \right] \tag{13}$$

The output equation is the following formula:

$$I_S = \frac{U_R}{R_S + R_I} \tag{14}$$

providing the relationship between the sensor current I_S and the variables of state, and following from equation (4) the relationship between the measured flow velocity v and the sensor current I_S:

$$\mathrm{v} = \left(\frac{\frac{I_S^2 R_S}{R_S - R_{SG}} - A_S}{B_S} \right)^{\frac{1}{n_S}} \tag{15}$$

Equations (11, 12, 13) with the initial conditions for the variables of state and together with equations (14) and (15) constitute the mathematical model of the measuring circuit shown in Fig. 1. It is a dynamic model of the third order, which is quite consistent with the conclusions presented in (Freymuth 1998). The model takes into account the dynamic parameters of an anemometric sensor, a PI controller and the operational amplifier with considerable gain. On the other hand, the dynamic parameters of sensor leads and differential amplifiers in the comparator circuit, characterised by very small gain, are neglected. Were those parameters also to be considered, the model would become much more complicated.

3.2. Results of model tests

The main aim of the model tests was to investigate the properties of the measurement circuits and to determine and optimise their metrological parameters, focusing mainly on dynamic phenomena.

The method applied consisted in iterative numerical solving of the system of equations for variable model parameters. This solution has the form of a computer simulation of system operation. MATLAB software was utilised in the modelling. The system of equations was solved using the numerical Runge-Kutty method of the fifth order. Parameters in the tests were close to those in real measurement circuits with typical sensors made of tungsten wire 3 μm in diameter. The parameters of the anemometric sensor are listed in Table 1.

The parameters of the measuring circuit are provided in Table 2. The parameters of an amplifier in the controller are those of operational amplifier OP 27 manufactured by PMI. It has the most favourable static and dynamic parameters. This amplifier was applied in real measuring circuits. The gain K_I is calculated for the predetermined value of the overheat ratio. The remaining controller parameters: k_C and r_C were obtained through modelling to find the optimum patterns in terms of the transmission band for the measuring circuit.

TABLE 1

Parameters of the sensor

TABLICA 1

Parametry czujnika

R_{S0} [Ω]	T_0 [K]	a_S [1/K]	A_S [A^2]	B_S [A$^2\sqrt{\text{s/m}}$]	c_S [A^{2}s]	n_S
5	293	$3.33 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$0.5 \cdot 10^{-3}$	$0.5 \cdot 10^{-6}$	0.5

TABLE 2

Parameters of the measuring circuit

TABLICA 2

Parametry układu pomiarowego

R_I [Ω]	K_U	U_0 [V]	R_C [Ω]	R_A [Ω]	k_A	τ_A [s]
10	2.5	10^{-6}	10^3	10^6	10^6	$15 \cdot 10^{-3}$

Each simulation procedure consisted in determining the steady-state for the predetermined set of parameters, then the system response to the preset excitation signals was sought. Step excitations were applied where a given parameter was varied by a predetermined value, afterwards it returned to the initial value. The behaviour of the measuring circuit was investigated in the conditions of step changes of the offset voltage ΔU_0 and flow velocity ΔV. The step function ΔU_0 is often applied in real measuring circuit to test the dynamic parameters. The following values were assumed: $\Delta U_0 = 0.1$ mV; $\Delta V = 0.1$ m/s.

The results of model tests are plots of the voltage U_S, resistance R_S, sensor current I_S and the velocity of medium flow v, derived from equation (15), for the predetermined parameters and excitation signals. Simulation results presented here were obtained for the overheat ratio $\eta = 1.8$, temperature of the medium $T_G = 293$ K and flow velocity $V = 5$ m/s. Simulation results for the preset step change in the offset voltage ΔU_0 are shown in Fig. 3, for the preset step change in velocity ΔV in Fig. 4.

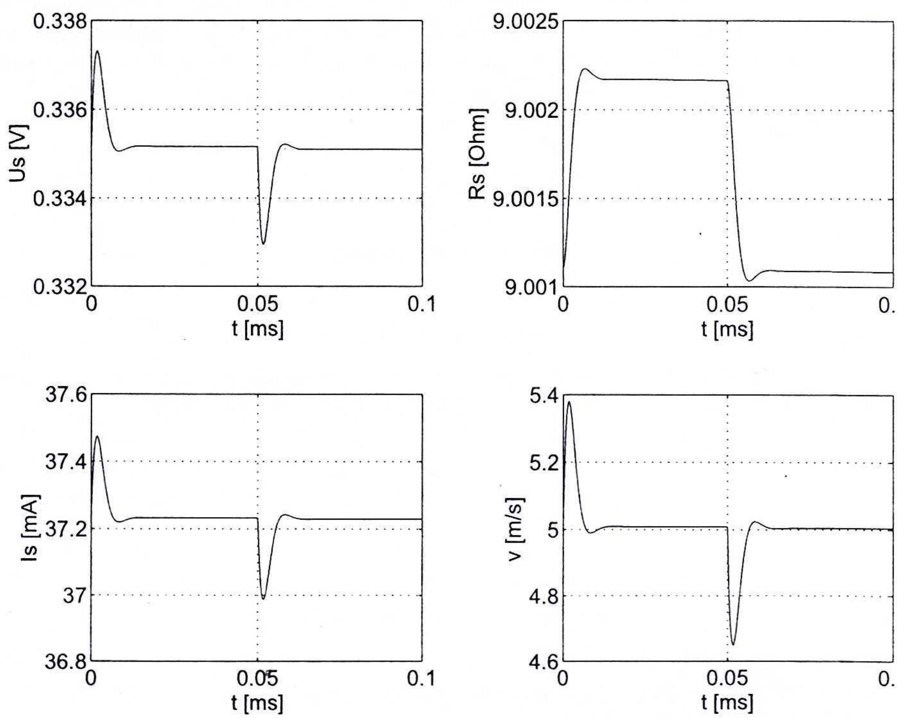

Fig. 3. Simulation results for the step function of the offset voltage

Rys. 3. Przebieg symulacji dla skoku napięcia niezrównoważenia

The transmission band of the circuit for the given parameters was determined in model tests. For the overheat ratio $\eta = 1.8$ and over the velocity range 0 to 20 m/s, the obtained transmission band was 75 to 115 kHz. When $\eta = 1.4$, the transmission band is about 70% of these values. Results obtained for the step changes of the offset voltage and velocity were similar, which justifies the application of the offset voltage step function to the testing of the system's transmission band.

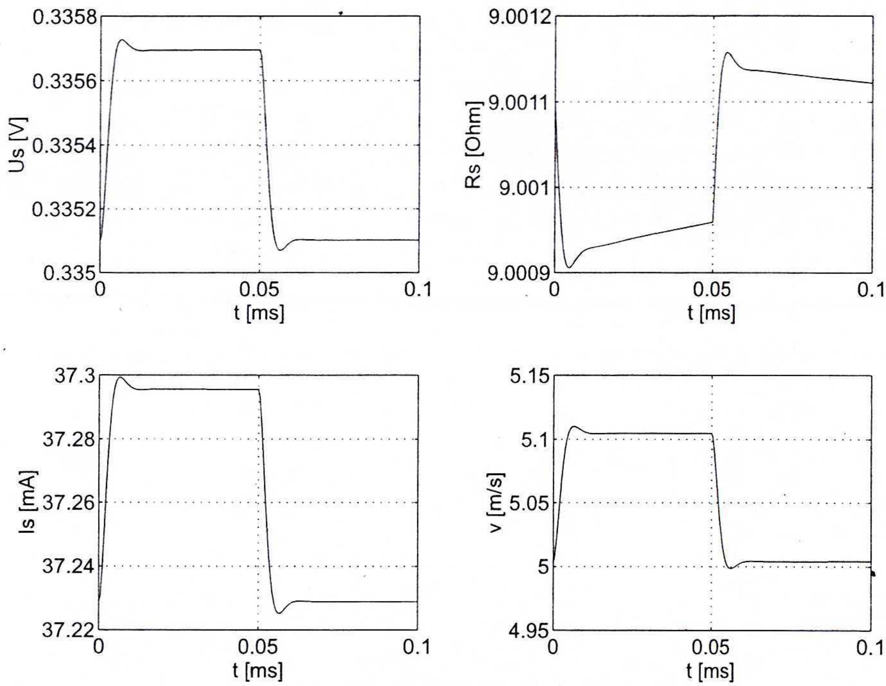

Fig. 4. Simulation results for the step function of flow velocity

Rys. 4. Przebieg symulacji dla skoku prędkości

4. Testing of the measuring circuit

The main aim of testing of the CTA circuit with four-point sensor resistance measurements was to measure and optimise the metrological parameters of the circuit and to check its possible applications. On the basis of analyses and simulation tests, a laboratory measuring circuit was built, complete with anemometric sensors (Ligęza 1997). The experimental set-up included a computer-controlled wind tunnel and a measurement data aqusition system. That system allows for signal recording at 12-bit resolution and a maximum sampling frequency of 10 MHz. The static characteristics and dynamic parameters of the circuit were investigated.

4.1. Measuring circuit

A block diagram of the measuring circuit in a CTA providing for four-point resistance measurements is shown in Fig. 5. Elements to be controlled are indicated with arrows. The circuit is based on the conceptual design shown in Fig. 1. It allows

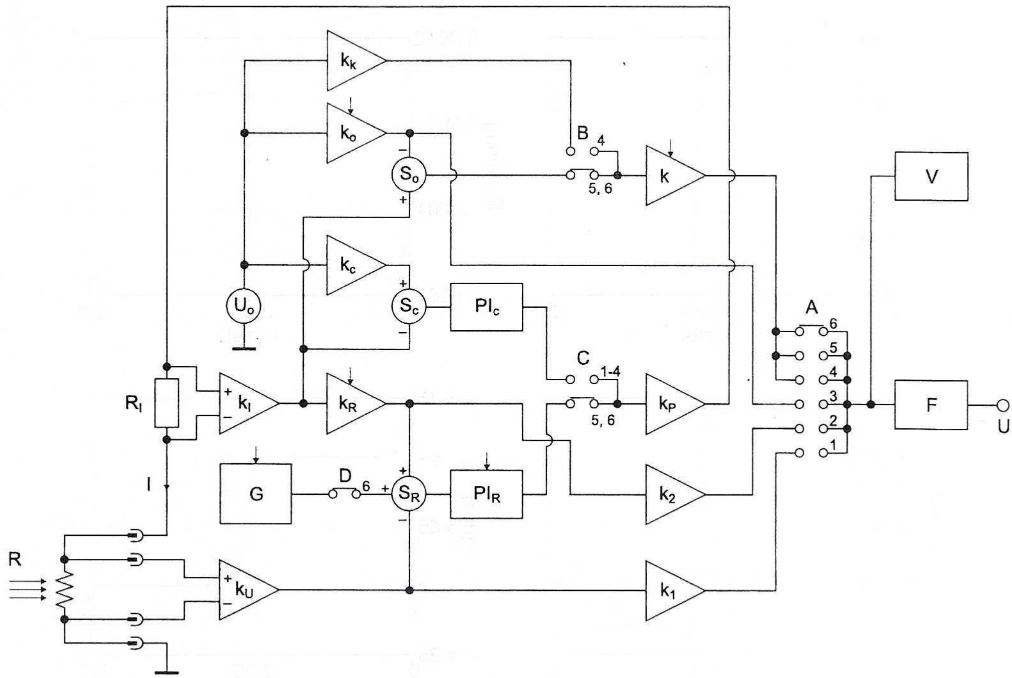

Fig. 5. Block diagram of the measuring circuit

Rys. 5. Schemat blokowy układu pomiarowego

for the sensing of several metrological functions, which can be selected with the switch ABCD:

1) measure the resistance of the "cold" sensor,
2) set the resistance of the hot sensor,
3) set the constant component to be subtracted from the signal,
4) set the output amplification gain,
5) CTA operation mode,
6) test the dynamic parameters of the circuit.

The CTA circuit consists of amplifiers of sensor voltage (k_U) and sensor current (k_I) signals, an amplifier of sensor overheating control k_R, a summation node S_R, a controller PI and a power amplifier k_p. For the purpose of testing the dynamic parameters of the circuit, a square signal generator G is connected to the summation node S_R. Output signal proportional to the sensor current from the amplifier k_I pass to the summation node S_0, where the constant component from the reference voltage source U_0 controlled with amplification k_0 is eliminated. Afterwards the signal is amplified in a controlled amplifier k and is sent to the output through a low-pass filter F and to the voltmeter V.

For functions 1 to 4, the measuring sensor R is supplied from a constant current source. In the summation node S_C, the signal proportional to the sensor current is compared with the preset value from the amplifier k_C. The PI controller stabilises the sensor current and maintains it at a predetermined level. That allows for the resistance of the cold sensor to be measured as well as the preset resistance of the hot sensor across the voltmeter V. Amplifiers k_1, k_2, k_k make it possible to read the measured values from the voltmeter in specified units.

For the purpose of the tests, hot-wire sensors with four-point leads were made. Accordingly, as the sensor current and voltage leads are separated, the effects of the leads' and joints' resistance on the sensor overheat level can be eliminated.

4.2. Static characteristics

The analysis of static characteristics of the measuring circuit involved finding the relationship between the output voltage and the velocity of the air-flow. The output voltage is the linear function of the sensor current, the proportionality factor being 0.1 V/mA. Flow velocity in the tunnel varied from 0 to 20 m/s and the ambient temperature was 20°C.

Tests were run on a sensor whose resistance at the ambient temperature was 5 Ω. It was made of tungsten wire 3 μm in diameter. Characteristics were obtained for two four-wire supplying cables, 2 m and 10 m in length. The resistance of a single wire was 0.12 Ω/m. In the measuring circuit the predetermined sensor overheating level in relation to its resistance at the ambient temperature measured in a four-point

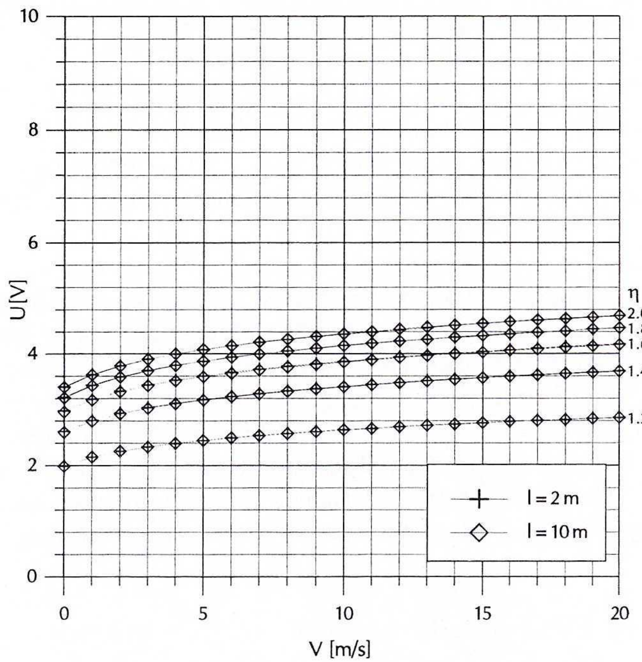

Fig. 6. Static characteristics for the four-point circuit

Rys. 6. Charakterystyki statyczne w układzie czteropunktowym

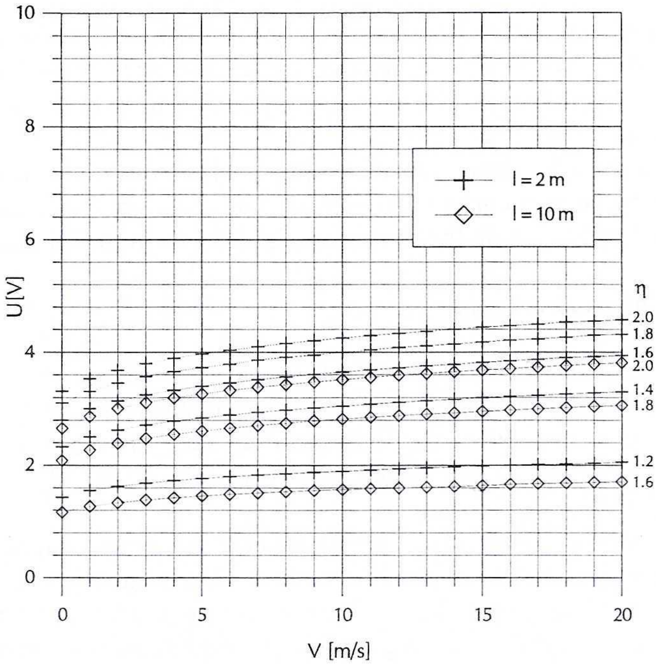

Fig. 7. Static characteristics for the two-point circuit

Rys. 7. Charakterystyki statyczne w układzie dwupunktowym

configuration would be preset. The overheat ratio values were: $\eta = 1.2, 1.4, 1.6, 1.8, 2.0$. Results of measurements of four-point systems taken for two supplying cables at various overheating levels are presented in Fig. 6. The characteristic curves obtained for the two cable lengths are identical, so the effects of cable resistance on the static characteristic of the sensor are eliminated.

For the sake of comparison, the characteristics of sensors with two-wire supplying cables were also determined. The voltage leads supplying the sensor were disconnected and the current leads in the circuit were shorted with the voltage leads. The overheat ratio was not changed. These measurements are the same as when testing conventional two-point CTA circuits in bridge configurations. Measurement results obtained for two-point circuits for two supplying cables at different overheat levels are presented in Fig. 7. The effects of cable resistance seem significant. To reach the preset sensor overheating levels in the two-point circuits, some compensating action will be required.

4.3. Testing the dynamic parameters of the circuit

Testing the dynamic parameters consisted in recording the response of the measuring circuit to excitation square signals of the CTA circuit offset voltage. The main aim of these tests was to find the transmission band for flow velocity measurements. Output voltage was recorded while the generator of square signals was on. Output voltage is the linear function of the sensor current, the proportionality factor being 0.1 V/mA. The frequency of the square signal was 10 kHz and its amplitude remained constant throughout all measurements.

The sensor and supplying cables used in tests in the four-point configuration were the same as those used to obtain the static characteristics. In the measuring circuit the sensor overheat level was set precisely in relation to its resistance at the ambient temperature measured in the four-point circuit. Two values of the overheat ratio were considered: η = 1.4 and 1.8 and three flow velocity values: 0, 5 and 20 m/s.

To obtain optimal response in terms of the transmission band, circuit adjustments were required each time. The system responses for the cable length l = 10 m, the overheat ratio η = 1.8 and three values of flow velocity are shown in Fig. 8, and for η = 1.4 in Fig. 9. The transmission band for η = 1.6 and over the flow velocity range 0 to 20 m/s was 70 to100 kHz. When η = 1.4, the transmission band would be 50 to 70 kHz. These results are very similar to those obtained in model tests.

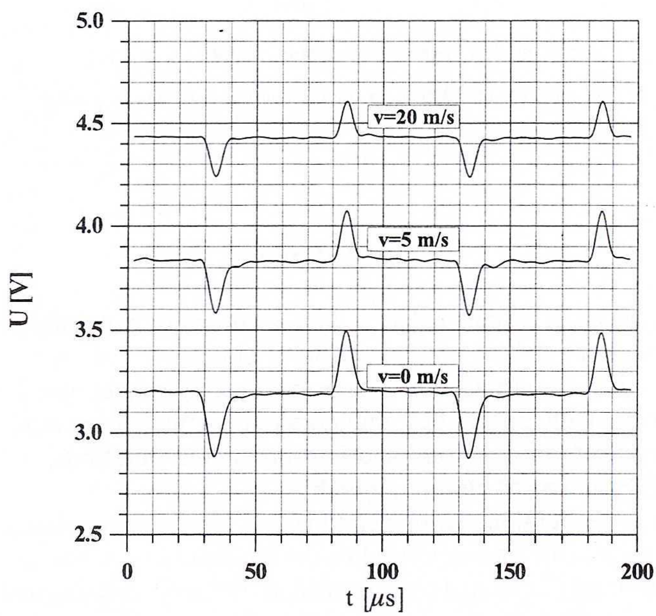

Fig. 8. System response to square excitations, η = 1.8

Rys. 8. Odpowiedź układu na wymuszenie prostokątne, η = 1,8

Noise parameters were also measured. The signal-to-noise ratio in the frequency band up to 100 kHz would be about 60 dB. Some optimisation action would be required before this value could be increased.

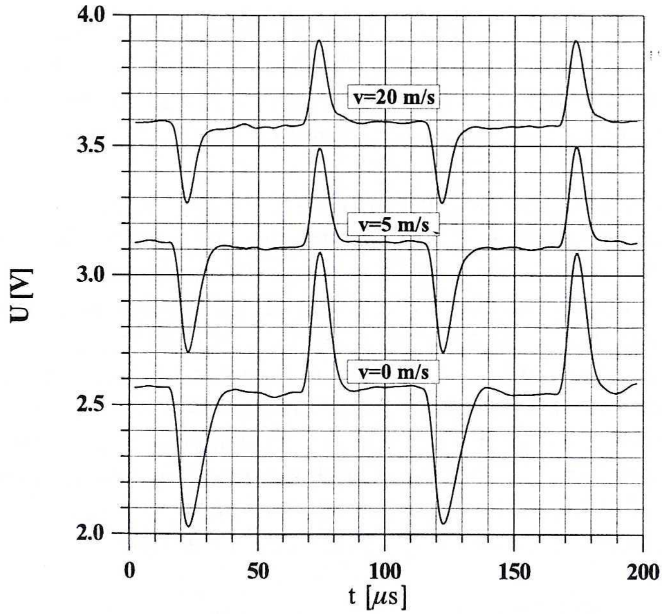

Fig. 9. System response to square excitations, η = 1.4

Rys. 9. Odpowiedź układu na wymuszenie prostokątne, η = 1,4

4. Conclusions

The investigated CTA circuit offers a new solution of the supplying system to anemometric sensors. The main features of this circuit are as follows:

- the effect of cable resistance on sensor overheat ratio is eliminated,
- stability of static characteristics, favourable dynamic parameters,
- sensor can operate in two-point and four-point configurations,
- controllability, open structure, modifiable.

In comparison to conventional bridge circuits, the static characteristics of this circuit have much more favourable parameters while the dynamic parameters are very similar. However, the measuring circuit had to be expanded. In many metrological applications, new circuit with four-wire supplying cable may replace bridge circuit. Measurement errors will be thus minimised and the measuring circuit will be easier to operate. In several applications these two options will be possible. However, in measurements of fast-changing flows and over a high frequency range bridge circuit may prove more adequate as they have smaller number of components, and their dynamic and noise related parameters are easier to optimise. The new circuit is therefore only an alternative for the bridge systems. The choice of the actual configuration to be utilised depends on the task assigned to the instrument.

Some features of the new circuit may allow for minimisation of errors and optimisation of the measurement procedures in several fields of anemometric applications:

- in measurements when the cables supplying the sensor are long, especially when the temperature in the cable surroundings may change considerably,
- in measurements when different types of supply cables are used,
- in measurements with the use of small-resistance sensors,
- in measurements at low overheat ratios,
- in measurements of slow flows,
- in specialised measuring circuits where the overheat ratio has to be precisely set and maintained continuously.

This circuit has already been utilised in measuring systems designed and constructed by the Author for laboratory tests (Ligęza 1997, 2000). This work is sponsored by the State Committee for Scientific Research, project 8T 10C 03220.

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