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CORRECT INTERPRETATION OF THE CTA MEASUREMENTS AT LOW OVERHEATS

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Summary: *The paper deals with an effect of dynamic adjustment on the behaviour of constant-temperature anemometer. The static dependence of the output anemometer voltage on the gain and the offset voltage of the amplifier was investigated experimentally. The DISA CTA bridge 55M10 was examined. Data were compared to the measurements performed at a Wheatston bridge without any amplifier. Applied model of the CTA feedback system fits the behaviour of the bridge satisfactory.*

1. Model of the CTA bridge

Principle of operation involves a feedback loop which maintains a sensor at an approximately constant resistance in a Wheatstone bridge. A simplified scheme of an constant-temperature anemometer bridge is present in fig.1.

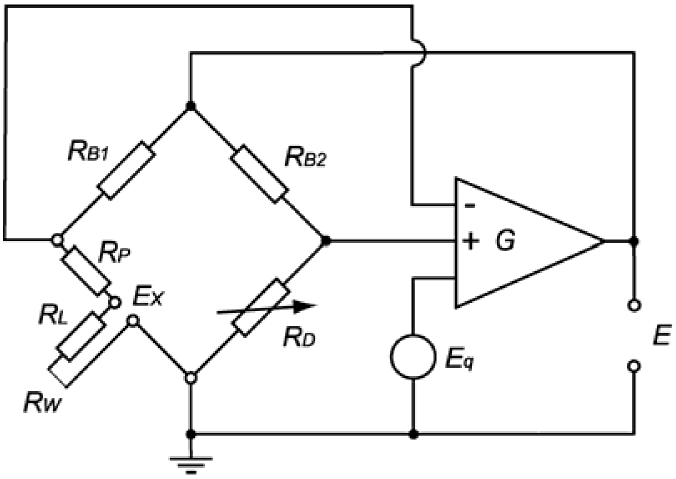

Fig. 1. CTA anemometer

Overheat ratio a is defined:

$$a = \frac{R_w}{R_0}. \tag{1}$$

Equation for the current I through the wire was derived by Perry and Morrison (1971):

$$I = \frac{G_A E_q (R_{B2} + R_D)}{(R_{B1} + R_\Sigma)(R_{B2} + R_D) + G_A [R_\Sigma R_{B2} - R_D R_{B1}]}, \tag{2}$$

where:

$$R_\Sigma = R_w + R_L + R_P. \tag{3}$$

In ideal case of $E_q \to 0$ and $G_A \to \infty$ will be R_w equal to the balanced value R_{wB}:

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$$R_{wB} \cong \frac{R_{B1}}{R_{B2}} R_D - R_L - R_P \quad ; \quad G_A \gg 1. \tag{4}$$

Then, we can define the „balanced“ overheat ratio a_B:

$$a_B = \frac{R_{wB}}{R_0}. \tag{5}$$

A wire voltage with respect to the Ohm law $E_w = I R_w$ will be from equation (2):

$$E_w = \frac{G_A E_q (R_{B2} + R_D) R_w}{(R_{B1} + R_\Sigma)(R_{B2} + R_D) + G_A [R_\Sigma R_{B2} - R_D R_{B1}]}. \tag{6}$$

Considering generalized form of the Collis–Williams heat-transfer law $Nu(T_m/T_a)^m = A + B\,Re^n$ we can derive implicit equation for the operating sensor resistance R_w:

$$\begin{gathered} \left[\frac{G_A E_q (R_{B2} + R_D)}{(R_{B1} + R_P + R_L + R_w)(R_{B2} + R_D) + G_A [(R_P + R_L + R_w) R_{B2} - R_D R_{B1}]}\right]^2 \cdot \\ \cdot \frac{R_w}{\pi l_w \lambda (T_w - T_a)} \left(\frac{T_m}{T_a}\right)^m = A + B \left(\frac{\rho u d_w}{\mu}\right)^n \end{gathered}, \tag{7}$$

where following properties:

$$\left.\begin{array}{l} T_w \\ T_m \\ \left.\begin{array}{l} \lambda \\ \mu \\ \rho \end{array}\right\} = f(T_m) \end{array}\right\} = f(R_w) \tag{8}$$

are functions of the R_w.

2. Experimental investigation

The CTA bridge of type DISA 55M10 was examined. Data were compared to the measurements performed at a manually balanced Wheatston bridge. Dependence of the wire voltage on the balanced overheat ratio is shown in fig. 2 and 3.

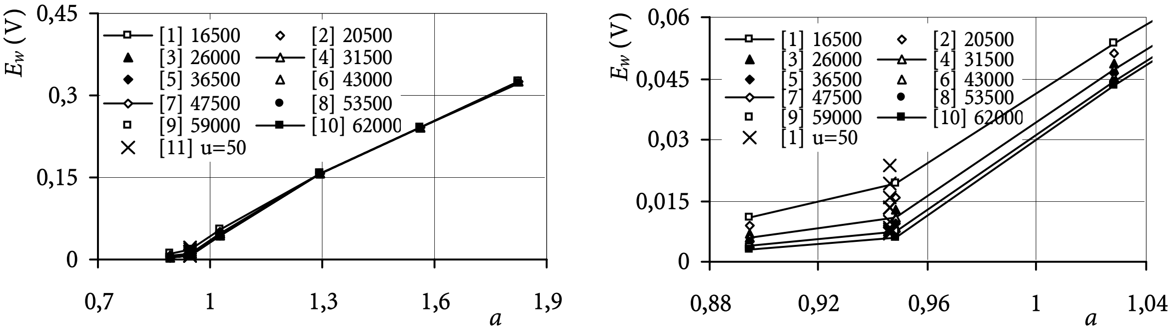

Fig. 2 and 3. Measured values $E_w = f(a_B)$ for zero flow velocity (u=0 m.s^{-1}) for gain: [1] G_A=16500; [2] G_A=20500; [3] G_A=26000; [4] G_A=31500; [5] G_A=36500; [6] G_A=43000; [7] G_A=47500; [8] G_A=53500; [9] G_A=59000; [10] G_A=62000 and [11] for flow velocity u=50 m.s^{-1}. CTA bridge 55M10.

Effect of the gain on the wire voltage is shown in the following graphs (fig. 4 and 5.).

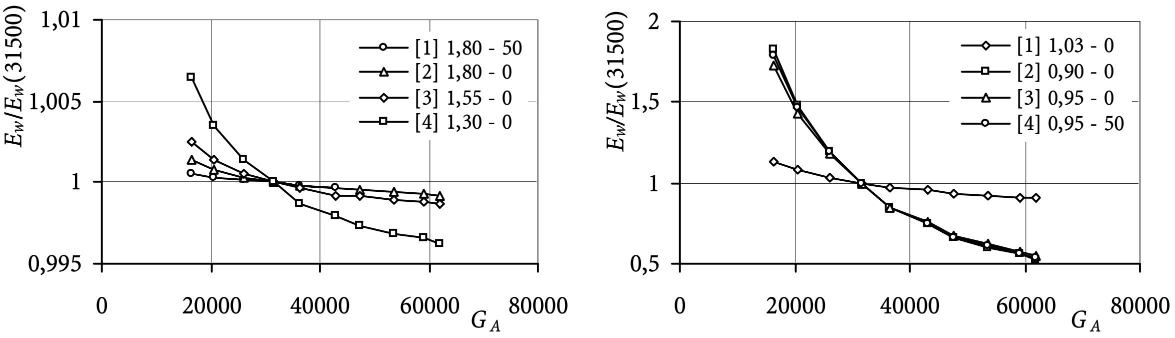

Fig 4 a 5. Measured values $E_w/E_w(G_A=31500)$ for the balanced overheat ratio and the velocity: [1a] a=1,80; u=50 m.s^{-1}; [2a] a=1,80; u=0 m.s^{-1}; [3a] a=1,55; u=0 m.s^{-1}; [4a] a=1,30; u=0 m.s^{-1}; [1b] a=1,03; u=0 m.s^{-1}; [2b] a=0,90; u=0 m.s^{-1}; [3b] a=0,95; u=0 m.s^{-1}; [4b] a=0,95; u=50 m.s^{-1}. CTA bridge 55M10.

A characteristic of the CTA bridge for balanced overheat ratio and adjusted gain and offset voltage is a result of the equation (6). Wheatston bridge measuremets in comparison with CTA anemometer measurements accompanied with CTA-bridge characteristics for all balanced overheat ratios are drawn in the next graph (fig. 5).

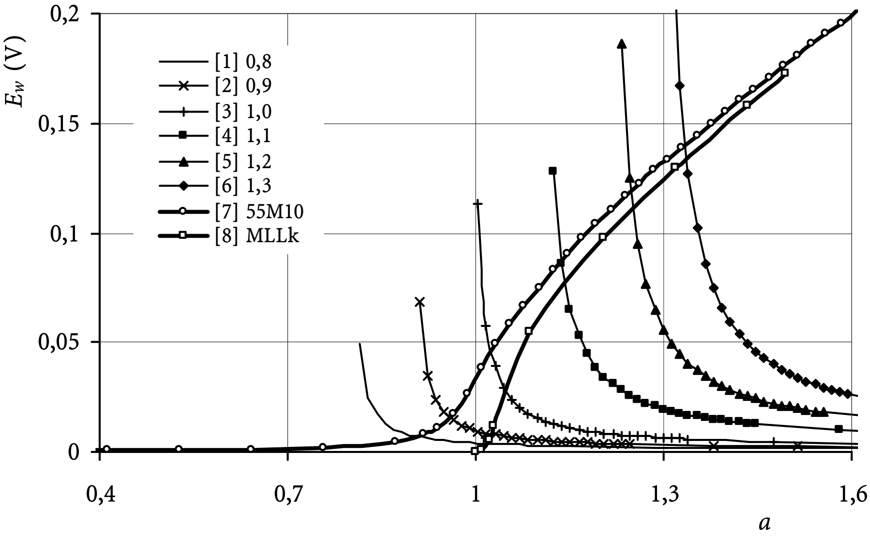

Fig 6. CTA-bridge characteristics $E_w=f(a_B)$ for gain G_A=31500 and offset voltage E_q=9,2e-4 V, for balanced overheat ratios: [1] a_B=0,8; [2] a_B=0,9; [3] a_B=1,0; [4] a_B=1,1; [5] a_B=1,2; [6] a_B=1,3. [7] Measured wire voltage $E_w=f(a_B)$ for velocity u=50 m.s^{-1} with DISA 55M10 for G_A=31500; E_q=9,2e-4 V and [8] measured wire voltage $E_w=f(a)$ with Wheatston bridge.

If drawn characteristics [1]; [2]; [3]; [4]; [5]; [6] are correct, the voltage of the intersection of each characteristic with the curve [8] has to agree with the voltage of curve [7] for balanced value of overheat ratio. From this condition one can determine the offset voltage of value E_q=9,2e−4 V.

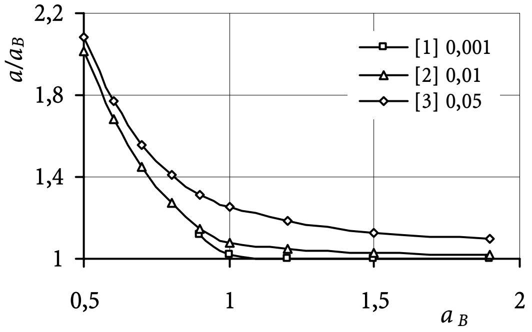

Fig 7. Ratio of the real and the balanced overheats. For offset voltage: [1] E_q=1 mV; [2] E_q=10 mV; [3] E_q=50 mV. Velocity is u=20 m.s^{-1} and gain G_A=31500.

Graph in fig. 7 illustates, that the overheat ratio deviation can be far from being negligible in case of real CTA anemometer measurements.

3. Conclusion

For use of any heat-transfer law in dimensionless form the operating sensor temperature has to be known. The correct wire temperature must be computed from the real value of the overheat ratio. Difference between the real overheat ratio and balanced one at low overheats is appreciable. The difference can be neglected only for middle and high overheats.

4. Acknowledgement

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5. References

Perry, A. E.,Morrison, G. L.: A study of the constant-temperature hot-wire anemometer. Journal of Fluid Mechanics, Vol. 47, 577-599. 1971.