THERMODYNAMIC SENSOR OF THERMAL RADIATION

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Abstract: This article deals with sensing of thermal radiation, rather change of thermal flux caused by thermal radiation component. For measurement the thermodynamic sensor in balance wiring is used. Function and possibilities of this type of sensor are described. These are demonstrated on measurement of thermal radiation unit step and transfer characteristic of the sensor.

Keywords: thermodynamic, radiation, sensor

1. INTRODUCTION

Up to date, thermodynamic system measurements are based on temperature measurement and subsequent evaluation of trend. For measuring of the temperature, several types of sensors with electrical output signal are used. These include thermocouples, resistive temperature sensors, thermistores, infrared and piezoelectric sensors. But description of the system by these sensors is based on quazi-stable state, which is not objective. Also in regular thermometers, their thermal capacity and loading by heat consumption for self-functioning are much more involved.

One of possible solutions is to use thermodynamic sensors (TDS). In contrast to aforementioned, they are able to evaluate directly the change in thermal flux from the steady state, which can be caused by all three means of heat transfer (conduction, convection and radiation). In addition, sensor does not affect its surroundings, as it covers its own energetic losses.

To prove one of thermal flux component change detection the TDS with thermo-radiation probe was designed and two measurements were performed. They were transfer characteristic measurement for different intensities of thermal radiation and response of step jump measurement. Results of these measurements form a base for concrete applications of TDS, for example optical barrier or detection of infrared light intensity change in time. [1]

2. THERMODYNAMIC SENSOR (TDS)

Thermodynamic sensor is an active sensor, which measures change of temperature difference or thermal flux. It keeps itself at constant temperature and compensates any change of temperature by increasing or decreasing of output voltage. At the same time, this change in output voltage represents the output signal of the device.

TDS is built up of assemblage of heating elements (for example resistors) in balance connection with real sensor body powered with input dependent on the temperature of the sensor. It senses changes in element temperature differences, or to be more accurate, in thermal flux of the examined system, as the result of measured outer impact.

Disruption of equilibrium is detected by bridge unbalance which is brought about by change in thermal conductivity of the environment or by addition of heat by an active element of measured system. Input change is subsequently evaluated by a comparator, that heightens/lowers its output voltage and through feedback, corresponding current is brought onto the bridge. This causes increase/decrease in power dissipation of resistors and proportionally to that, thermal losses at resistors are changed. The measurement consists of two phases – stabilization, when thermal equilibrium is established in the system, and maintaining, when equilibrium is kept by changing of input power. This way, heat needed for re-setting of equilibrium is added into the system. This principle of thermal equilibrium maintenance is also termed as balance heater.

Sensor is applicable for sensing such quantities, which lead to disruption of its equilibrium. TDS allows contactless measurement. Actual application of such sensor is in measurement of flow rate, determination of impurities in liquids or direct sensing of thermal radiation. Experiments described below were conducted to determine possibilities of the last application [1] [2] [3].

2.1. TDS OF THE FIRST KIND IN BRIDGE WIRING

This kind of sensors works with constant temperature. If the temperature is changed by outer impact, sensor covers the difference, while input voltage corresponds with the intensity of the activity causing temperature the change. Two types of the first kind TDS are distinguished according to bridge arrangement – symmetric and asymmetric. These differ mainly in setting of operating point temperature and in response [4].

2.2. TDS OF THE SECOND KIND

Unlike the TDS of the first kind, TDS of the second kind do not work with a constant temperature, but constant difference of temperature, or rather constant thermal flux. This is secured by two thermo-probes with different resistivity. Disruption of equilibrium is also indicated by difference of input power needed for its maintenance. TDS of the second kind is universally applicable for a broad range of examined object activities [4].

3. PROPOSAL OF THERMAL RADIATION TDS

Function of thermodynamic sensor for thermal radiation is conversion of absorbed heat radiation into voltage. Constant thermal flux is established between the resistive elements of the probe. Response of the sensor is induced by addition or removal of thermal energy. Due to patent proceedings, detailed scheme cannot be published, therefore only block diagram is shown.

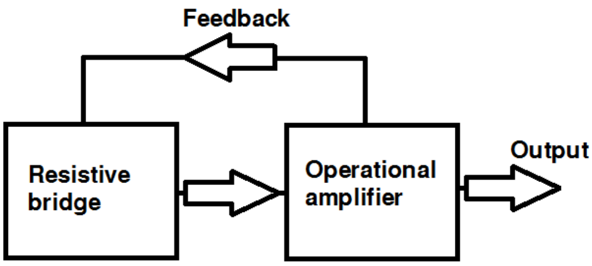

Figure 1: Block diagram of the thermodynamic sensor.

3.1. THERMAL RADIATION PROBE

The probe is realized on a ceramic substrate for its good thermal conductivity, which increases the sensitivity and lowers response time. It is comprised of two voltage dividers made of heating platinum elements, each placed at one side of the substrate. Platinum was chosen for good properties in broad range of measuring conditions (200 – 800 °C) and easy defined application by screen-printing.

Selection of suitable probes was based on the conformity of the platinum elements. The closer the values of resistivity, the higher the sensitivity of the probe. For reduction of response time, the probe was attached to a cooler (fig. 2).

Figure 2: Probe of TDS attached to cooler.

4. MEASUREMENT OF THE THERMODYNAMIC SENSOR

4.1. MEASUREMENT OF THERMAL RADIATION TDS RESPONSE TO UNIT JUMP

The task of this measurement was determination of sensitivity and response time for different distance between the sensor and radiating source.

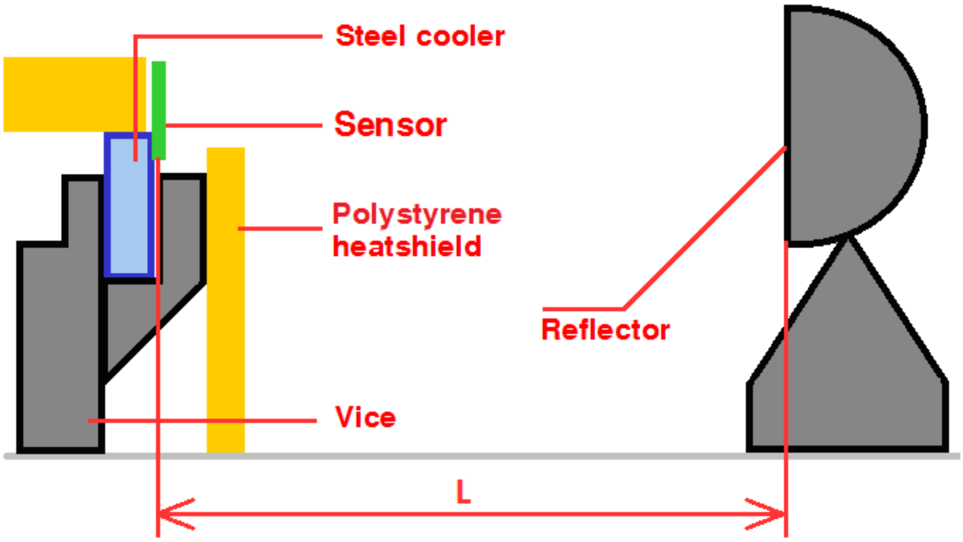

Figure 3: Measuring system organization for TDS unit jump response measurement.

Measurement was conducted in laboratory under standard illumination for distances of l = 10, 40 and 70 cm. Light bulb equipped with a reflector was used as a radiation source. For simplification, only the light bulb and the reflector were assumed as the radiation sources. The light bulb was considered as a spot source and the reflector as a perfectly reflective

Power P_B from a spot source in distance of l at the unit area can be calculated as:

$$P_B = \frac{P}{4\pi \cdot l^2} \quad \left[\frac{W}{m^2}\right], \tag{1}$$

where P is power of the spot source and l is distance from the source, or radius of a spherical surface.

Reflected part P_{Ref} of the radiation is then:

$$P_{Ref} = \frac{0{,}5P}{\pi \cdot r^2} \quad \left[\frac{W}{m^2}\right], \tag{2}$$

where r is a reflector radius.

For calculation of incident power at the probe, the relation assumes form of:

$$P_{Č} = S_{Č}\left(P_B + P_{Ref}\right) \quad [W], \tag{3}$$

where $P_{Č}$ is incident power at the probe and $S_{Č}$ is area of the probe

From the response of sensor input voltage under irradiation of probe by given power, sensitivity can be calculated as the ratio of difference in output voltage and difference of input power (eq.1).

$$K = \frac{\Delta U_{OUT}}{\Delta P_{Č}} \quad \left[\frac{V}{W}\right], \tag{4}$$

where ΔU_{OUT} is difference in output voltage and $\Delta P_{Č}$ is difference of incident power at the probe.

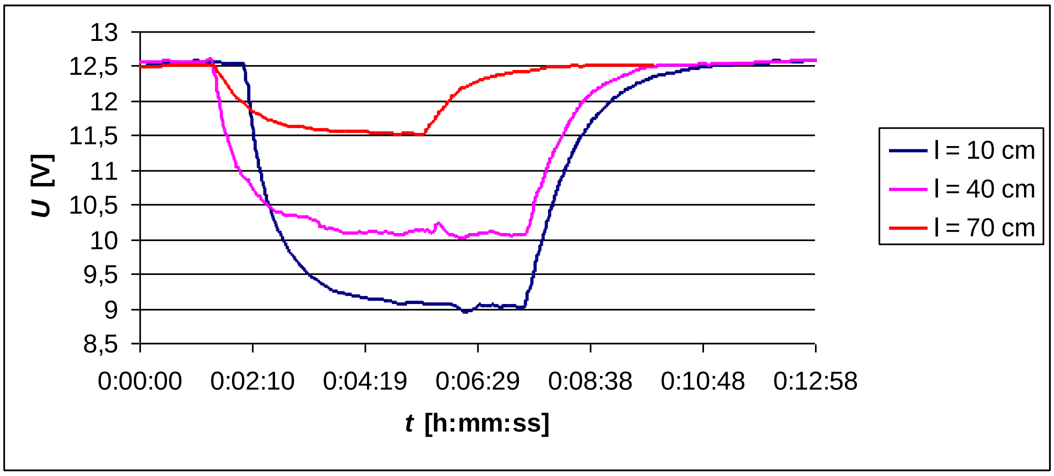

Figure 4: Unit jump response for different distances of the source.

l [cm]	τ_{ON} [s]	τ_{OFF} [s]	*k* [$V \cdot W^{-1}$]
10	43	70	23,7
40	43	55	41,58
70	49	60	19,38

Table 1: Sensitivities *k* for source distances *l* with reflector start τ_{ON} and stop time τ_{OFF}.

As seen in table 1, experimentally, quite high values of response time were determined. Higher values of τ_{OFF} are probably caused by permanent thermal radiation of the lamp, or by slow cooling of the measuring system. Effect of this could be lowered by attaching the probe to a bigger cooler [1].

4.2. Measurement of transfer chracteristics of thermal radiation TDS

Transfer characteristics were measured continuously for reflector distance of *l* = 10, 20, 30, 40, 50, 60, 70 cm in both directions. The change of distance was made after the stabilization of the sensor at the new steady-state. TDS output voltage was recorded by a computer.

Form the course of the output voltage in time, hysteresis is apparent for return way to the probe. This was probably caused by heat accumulation in the system. Exponential dependency of the sensor response to the distance was received, which corresponds with the transferred power decreasing with square of distance.

Measurement errors might have been caused by air movement in the room, change in the room temperature, imperfect direction of the reflector or by electromagnetic interference [1].

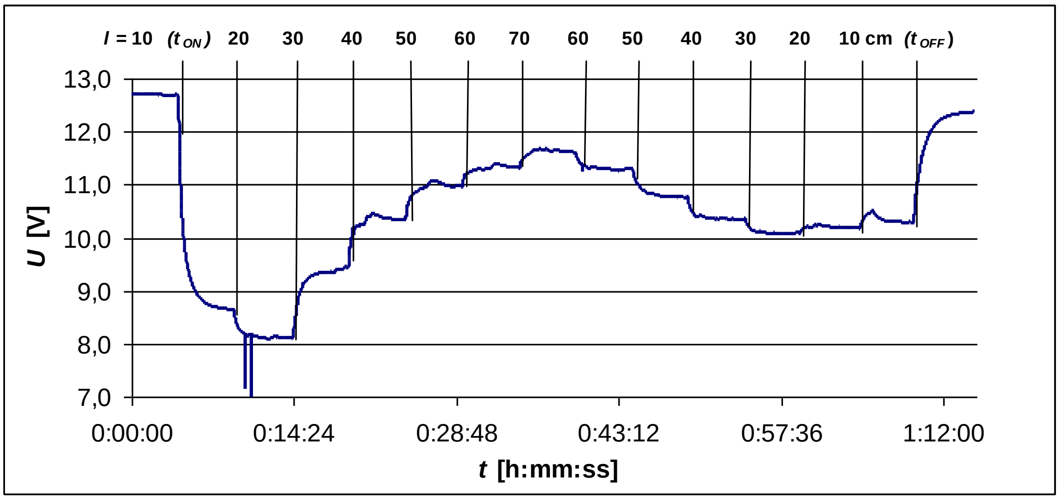

Figure 5: TDS transfer characteristic of thermal radiation.

5. CONCLUSION

In the experiments described above, the thermodynamic sensor application for thermal radiation detection using original principles based on balance equilibrium and evaluation of thermodynamic system changes was verified. The probe and the TDS were made by thick-film layer technology for good thermal conductivity and possibility of motive creating by special pastes.

Measurement showed high sensitivity of the sensor. Found out values of sensitivity are just informative because of rounding. As heat transfer losses and secondary heat sources were neglected, the real sensitivities are higher. Despite the best stable setting the large time constants of the sensor were measured (tens of seconds).

The experiment also showed that optimally balanced sensor reaches high sensitivity. With appropriate construction, sensed quantity can be selected and suppression of unwanted influences is possible. General applicability of TDS is a great advantage, but it brings about necessity to set each measurement.

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