Method and Apparatus for Measuring of the Heat Flow Density in Soil

V.A. Kulikov [1], K.A. Nikitin [2], S.G. Seletkov [3], Y.K. Shelkovnikov [4]

[1–3] Department of Computer Engineering, Kalashnikov Izhevsk State Technical University, Izhevsk, Russia
E-mail: [1] kulik00@istu.ru, [2] nikitin.a.kirill@gmail.com, [3] s.g.seletkov@mail.ru
[4] Laboratory measuring systems, IM UrDRAS, Izhevsk, Russia
E-mail: [4] evshelk@mail.ru

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Abstract. Temperature gradient and the thermal conductivity of the soil is measured by the three-phase thermo-converter. Density of the heat flux is calculated by the Fourier's law. The design of the sensor circuit and the measuring device are presented. The ability to measure of the heat flux density in the soil caused by the dissipation of heat from the heating duct, confirmed experimentally.

Keywords: Temperature, thermal conductivity, heating, heat flow density in the soil

INTRODUCTION

In most cases, heating of buildings and structures in Russia is carried out by supplying hot water conduits recessed into the soil (h eat pipelines) from thermal energy centers. The effectiveness of this method of heating depends largely on the condition and quality of thermal insulation of heating pipes. Currently, assessment of heat pipelines is carried out during the energy audit using thermal imaging units [1]. The devices mentioned make measurements of the surface temperature of the soil, which depends largely on the air temperature which surrounds the device and introduces a significant readings random error.

The paper proposes a method and a device allowing to measure the heat flux density in the soil, and excluding the impact of air above the track in the heat readings.

METHOD FOR MEASURING DENSITY OF HEAT FLOW IN SOIL

Measuring the heat flux density is based on Fourier's law. [2]

To perform the calculation temperature of soil is determined in its two points located on one vertical above the thermal route (Fig. 1). Then the heat flux density is calculated by the formula:

$$q = \lambda \frac{\Delta T}{l}. \tag{1}$$

The formula (1) denotes: ΔT – difference of temperatures at two points of measurement; l – distance between the temperature measuring points; λ – coefficient of thermal conductivity of the soil.

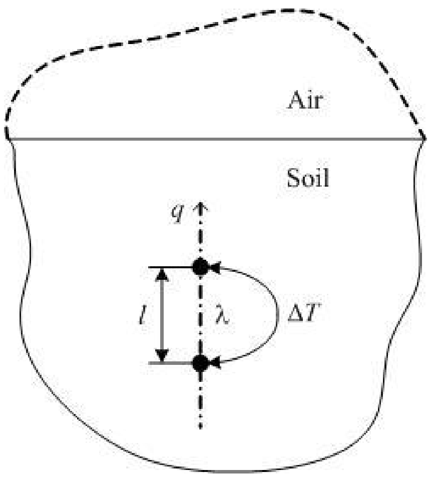

Figure 1. The circuit of measuring of heat flow density

Dynamic method of linear heater [3, 4] is selected for the measurement of the thermal conductivity coefficient of the soil (the "hot wire" method [5, 6]). The thermal conductivity coefficient λ is determined by the formula:

$$\lambda = \frac{P}{4\pi L \Delta T_{\lambda}} (\text{Ln}(\tau_2) - \text{Ln}(\tau_1)). \tag{2}$$

The formula (2) indicated: P, L – the power and the length of the heater; ΔT_{λ} – change of the heater temperature in the interval between time points: τ_1, τ_2. Registration of the soil temperature values τ_1 and τ_2 is performed on the linear portion of the function of temperature versus time measurements (Figure 2).

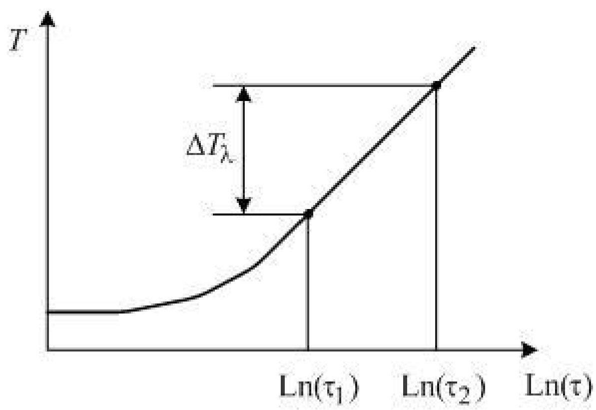

Figure 2. Determining the value ΔT_{λ}

To eliminate the influence of the edge effect a certain relation between the size of the length L and the diameter D of the heater must be fulfilled [7]:

$$\frac{L}{D} \geq 30. \tag{3}$$

THE SENSOR CONSTRUCTION

To measure the temperature ΔT and the thermal conductivity coefficient λ there used three-phase thermal resistance inverter (RTC) constructed as a cylinder (Fig. 3) [8]. It contains three coils: 1, 2, 3 of copper microwire, arranged in a single layer coil to coil on the inner wall of the protective tube 4. Coils 1 and 3 are RTC sensors for measuring temperature differences ΔT and localized along the length of the sensor. The coil 2 is used for measuring the thermal conductivity λ and is simultaneously the heater and sensor element for measuring the RTC temperature difference ΔT_{λ}.

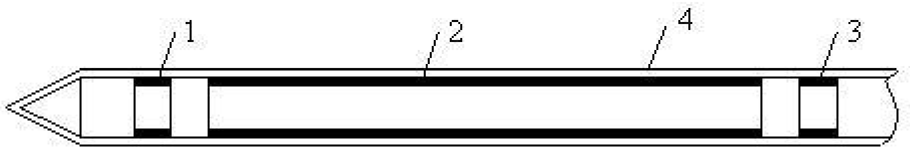

Figure 3. The construction of the heat flow density measuring sensor

Location of coils on the inner surface of the tube provides a low thermal resistance between them and the soil in the direction of the sensor radius. This ensures the total time of the measurement of the heat flux in the soil no more than two minutes.

THE DEVICE DIAGRAM

The authors have developed a device to work with the sensor. Its block diagram is shown in Figure 4.

The device contains three measuring channels to provide connection of the sensor coils: 1, 2, 3. Each channel includes a resistance-voltage converter (Converter), a normalizing voltage amplifier (Normalizing amplifier) and a low pass filter (Analog filter). All channels are connected to the ADC (ADC). Digital-to-analog converter (DAC) is used to control the sensor coil current . The measurement process is under control of a controller (MCU), which also calculates the heat flux density value and outputs the results on a LCD-display. The device model is made in the case of portable performance. At the same time a modern element base is used of and microcontroller ARM-architecture is applied.

EXPERIMENTAL RESULTS AND DISCUSSION

Device presetting with a sensor and its tests were carried out under laboratory conditions.

It is found that the scheme of the device on all channels provides a temperature resolution of 0.001 K, which provides measurement of values ΔT and λ with a sufficient accuracy for the task consisting in evaluating the heat losses from the heat carrier.

In the field conditions in April measurement of the heat flux density produced in the soil of heating pipeline at several depths from the surface. Near the surface to a depth of 0.5 m dependence of the results on the daily fluctuations in air temperature is well observed, while it decreased as the deepening probe. Measurements of heat flow density were carrying out at the same depth in the soil for two variants of the state of the heating pipeline. In the first case the heating pipeline contained no damage of thermal protection, and in the second case, the thermal protection was damaged.

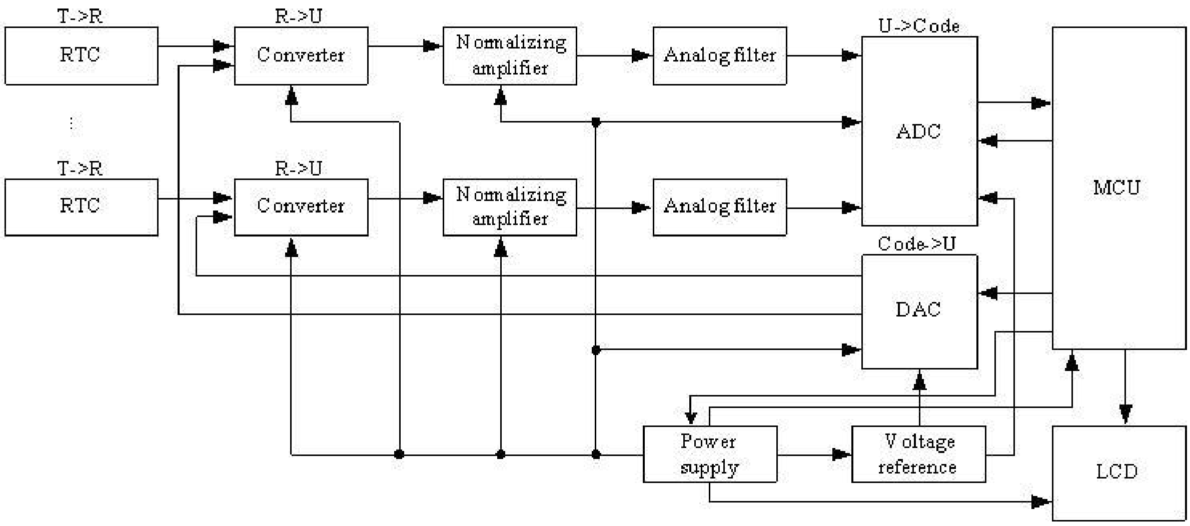

Figure 4. Block diagram for measuring heat flow density

In-situ measurements of soil temperature at different depths using these methods and device have established the value of the heat flow and its losses. If there was no damage to the track, the density value was 9.9 W/m^2, and in the presence of damage – 27.1 W/m^2. Thus, the absolute values of the thermal losses have been defined as well as the values of heat losses, characterizing their increase in case of heating pipeline damage.

There have been several measurements at the site of a heating pipeline with normal thermal insulation along the pipeline. Heat loss values were within 10 % with a probability of 0.95. It was found that the differences in the instrument readings are due to the heterogeneous composition of the soil, the presence of fragments of bricks, pebbles, broken glass. In general, the instrument readings in all cases are not contrary to the theoretical, and observed anomalies had reasonable explanations.

CONCLUSION

The authors have proposed and experimentally tested a modification of gradient method for measuring of the heat flux density in the soil on the basis of multi-zone thermal resistance converter of cylindrical structure. In the proposed execution the method, the technique and device implementing it allow measuring the heat flux density in the range of values corresponding to the heat dissipation of the heating mains, intended for heating buildings. The device allows to effectively identify areas with broken thermal insulation. The prospect of its further development and bringing to the industrial version is confirmed by experts on energy supply of buildings and structures.

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