VACUUM-TUBE AND TRANSISTOR INSTRUMENTS FOR INVESTIGATING THERMAL CONDUCTIVITY BY MEANS OF A LINEAR HEAT SOURCE

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A description is given of the construction of two instruments for determining the thermal conductivity of building materials. In both instruments a thermocouple serves as a linear heat source of constant power. The circuit of the first instrument is based on vacuum tubes, and the second on transistors. Both instruments have been used to investigate materials at positive and negative temperatures.

In the new variants of the method of investigating thermal conductivity using a linear source, a thermocouple serves both as a thermometer and a heat source. Unit length of both electrodes of the thermocouple must then have identical electrical resistance. The electrodes are butt-welded, so that they extend along a single axis. This kind of weld is obtained by discharge of a bank of electrolytic capacitors. For example, for welding a thermocouple of chromel and constantan wire of thickness 0.72 mm and 0.6 mm, discharge is required of a bank with a capacitance of 5400 microfarads, at a charge voltage of 40–80 volts.

The thermocouple is attached to the specimen of material being examined during its preparation, or is squeezed between two specimens (twin pieces). The thermocouple is heated by alternating current. The ac voltage of the heating current does not enter the circuit for measurement of the thermal emf: it is blocked by an electrical filter. As the thermal emf increases, and with it the temperature of the heat source, the thermal conductivity is calculated from the well-known formula of [1].

In the tube instrument (Fig. 1) a voltage of 220 V is supplied to the thermocouple through a step-transformer and baretter. There was provision for changing the thermocouple heating current from 0.3 to 1.2 A by connecting baretters in parallel. The required heating current was set up before the start of the test in a resistor simulating the resistance of the thermocouple.

The merit of this instrument lies in the simplicity of the principle of operation. The basic defects are the impossibility of automatic recording of the thermal emf by available automatic potentiometers and the low degree of stabilization of heating current afforded by a baretter. The over-all error of measurement is estimated to be 5% of the measured quantity.

The reason why automatic recording of the emf on existing potentiometers is impossible is as follows. The thermocouple heating current and the useful transformed signal at the input to the electronic amplifier of the potentiometer have the same frequency. The thermocouple heating current is a stray signal as regards the useful transformed signal at the potentiometer amplifier input, and may exceed the measured thermal emf many times. The phenomena arising in an automatic potentiometer when a large stray signal is present at its amplifier input have been described in the literature [2].

The noise immunity of the electronic autocompensator may be increased in two ways, by altering the frequency of transformation of the constant signal at the input to the electronic potentiometer amplifier, or by increasing the frequency of the heater current. In practice it is simpler to use an increased frequency in the range 3–5 kHz for the thermocouple heater. To obtain current of this frequency a voltage converter with a master oscillator is used, by means of which the transistors of the power amplifier (Fig. 2) are controlled. The master oscillator is made up of transistors T_5 and T_6 in a push-pull circuit with self-excitation: T_5 and T_6 being in a common emitter arrangement. A square-wave control voltage is supplied from a secondary winding of transformer Tr_2 to the bases of the triodes of the power amplifier. The latter is made up of transistors T_7 and T_8 in a common collector arrangement. This permits inclusion of a low-resistance load (the thermocouple) and a current up to 5 *a* is obtained. The transistors of the master oscillator and of the power amplifier operate in the key mode which achieves a high efficiency of voltage conversion. When the instrument is switched on, a considerable bias created by the voltage divider R_{12}-R_{14} appears at the base of transistors T_5 and T_6, as a result of which the output resistance of the transistors decreases and a current appears in the collector circuits. Because of differences in the electrical parameters of the transistors, the currents in the arms of the collector winding of transformer Tr_2 will be different, and a difference current will appear, creating a change in the magnetic flux of the transformer. The base winding is included so that further current increase occurs in the transistor with the larger collector current and cut-off in the transistor with the smaller collector current. When one transistor is fully on and the other fully off, the rate of change of the magnetic flux becomes zero, producing a sharp decrease in the currents in the windings and creating an emf of opposite polarity in the windings.

For operation of the master oscillator and the power amplifier in push-pull, the transistors must be selected as regards amplification and initial collector current. The saturation induction of the core of the master oscillator transformer determines the frequency of the circuit, and the degree of rectangularity of the hysteresis loop influences the losses and the switching speed of the transistors. The most suitable material is 50-NP Permalloy of toroidal shape.

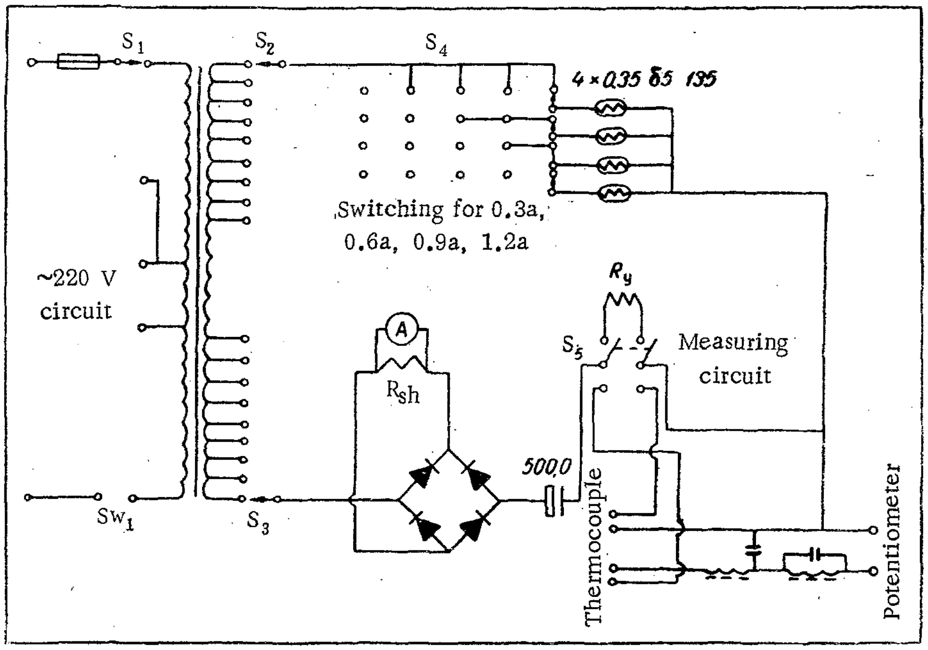

Fig. 1. Circuit diagram of the tube instrument.

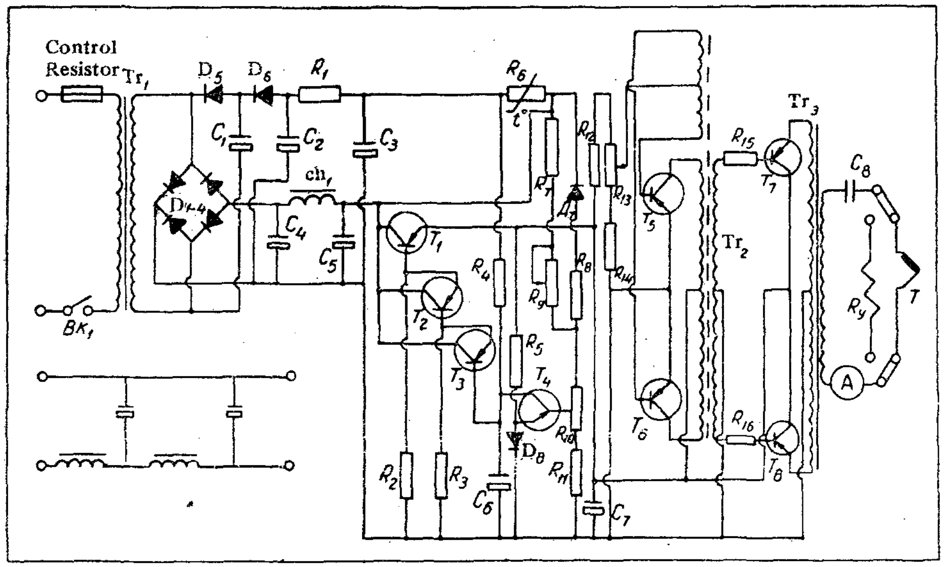

Fig. 2. Circuit diagram of the transistor instrument.

Thermal Conductivities of Building Materials

Material	Density in the absolutely dry state, kg/m^3	Moisture by weight, %	Thermal conductivity, W/m · degree, at temperature, °C		
			0	—10	—30
Silicate concrete	2100	0	1.14		1.14
		5	1.92		2.36
	1800	0	0.99		0.99
		8.7	1.66		1.89
	700	0	0.15	0.15	0.15
		6	0.23	0.24	0.26
Volcanic slag concrete	1030	0	0.27	0.27	0.27
		12	0.39	0.37	0.42
	850	0	0.22	0.22	0.22
		9.8	0.28	0.32	0.32
		14.5	0.35	0.38	0.44
Perlitic sand concrete	1000	0.	0.35	0.35	0.35
		6.5	0.41	—	0.45
		10.0	0.45	0.49	0.54
	830	0	0.23	0.23	0.23
		6.5	0.28	0.29	0.30
		13.0	0.33	0.35	0.42
Foam slag pyroceram	600	0	—	—	0.33
		15.1	—	—	0.38
	500	0	—	—	0.28
		27.5	—	—	0.37

The power amplifier, which has a small output resistance, allows us to increase the efficiency of the complete instrument and to improve the load characteristics of the converter. The control voltage supplied to the input of the power amplifier transistors insures that they operate in the key mode. A low voltage supply was chosen for the circuit because the power amplifier circuit with common collector requires less supply voltage. Smooth control of the heater control was accomplished by varying the bias voltage in the base circuit of the master oscillator by means of the resistance R_{13}.

The instrument power supply was obtained under steady conditions from a 220 V alternating current, and under field conditions from a 12 V storage battery. In the first case the voltage from the rectifier, which is arranged in a bridge circuit of diodes D_1–D_4, is supplied to the voltage stabilizer. The stabilizer has a closed control circuit made up of transistors T_1–T_4, and contains the control element (T_1), the mismatch signal amplifier (triodes T_2–T_4), and a standard reference source (stabilitron tube D_8). Stabilitron D_7 is the source of stable auxiliary voltage.

The transistors T_2 and T_3 operate as emitter followers, achieving a large input resistance and large current gain. This permits large currents to pass through the control transistor without increase of the base current of transistor T_3. The resistors R_2 and R_3 are inserted so that transistors T_2 and T_3 do not cut off when the load current drops to zero.

The instrument contains a two-section G-shaped filter. To avoid any pickup in the filter its inductances were located in a multilayer screen of Permalloy and copper with their axes mutually perpendicular and with some distance between the two. The whole circuit was wired with shielded wire. The transformer and the rectifier choke coil were located in a separate shielded compartment.

We have made extensive use of the above-described vacuum tube and transistor instruments to investigate the thermal conductivity of building materials, both dry and moist, under conditions of positive and negative temperature. They were mounted in such a way that they could easily be transferred to the location of the tests—to a thermostat, and a cooling chamber.

The test specimens with thermocouples attached to them were located in a thermostat or a cooling chamber at the temperature at which it was desired to determine the thermal conductivity. When we used the vacuum-tube instrument, measurement of the emf was carried out by means of an R-307 potentiometer and a galvanometer. For automatic recording of the thermal emf with the transistor instrument we used an EZ-2 automatic electronic potentiometer.

The high sensitivity of the R-307 and EZ-2 potentiometers allowed us to investigate the thermal conductivity of moist materials at negative temperatures. The specimens were located in the cooling chamber, where they were kept until the required temperature was established. The heating of the thermocouple was carried out by steps of a fraction of a degree in order to avoid the possibility of thawing the ice because of thermal action. In this way investigations were made of wet gas- and foam-concrete, concrete with light natural aggregates, heavy silicate concrete, and foam slag pyroceram. The specimens were investigated in the dry state and at room temperature by a steady-state thermal conduction method. The test indicated that the accuracy of determining the thermal conductivity by the above instruments was quite satisfactory.

The results of some of our experiments are set out in the table. We are publishing these data since the materials investigated, like the majority of other building materials, have not hitherto been investigated at negative temperatures.

The instruments are also suitable for the investigation of materials at high temperature, where the thermocouple may still serve its purpose. The specimens may be kept at a controlled temperature, for example in a furnace, a reaction chamber, etc. Then the thermocouple is heated to an extent which can be recorded reliably by the available instrument.

REFERENCES

1. L. F. Eyankelev and V. S. Roife, IFZh, [Journal of Engineering Physics], 8, no. 4, 1965.

2. D. E. Polonnikov, Electronic Amplifiers of Automatic Compensators [in Russian], Fizmatgiz, Moscow, 1960.

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