AUTOMATIC MEASUREMENT OF BOUNDARY LAYER TEMPERATURE AND HUMIDITY FIELDS

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Inzhenerno-Fizicheskii Zhurnal, Vol. 10, No. 3, pp. 321–325, 1966

UDC 532.526

A method of automatic measurement of the temperature and humidity fields in a boundary layer is described. The results are made available in the form of automatically drawn graphs on a scale convenient for determining boundary layer thickness.

The study of heat and mass transfer processes on the basis of analysis of temperature and humidity in the boundary layer has a number of advantages over other methods, but it is associated with numerous laborious and time-consuming measurements.

With the development of Smol'skii's much-cited equipment [1], the problem of automation of temperature and humidity field measurements has been solved in principle. In that equipment, however, electronic circuits are employed, and their use requires special knowledge. The construction of equipment of that kind in the ordinary thermophysical laboratory presents decided difficulties, and therefore the development of a simple means of automating the boundary layer measurements remains a real problem.

The present paper describes a method of automatic measurement of temperature and humidity fields in the boundary layer, the results being made available as automatically drawn graphs on a scale suitable for determination of conventional boundary layer thickness.

The method permits the automation of those typical devices which have been described in detail in the literature [2–5] and consist of four basic elements: head, coordinate positioner, measuring element, and device for determining the instant of contact of the sensor with the body surface. To achieve this it is sufficient to make the following simple changes: the measuring element is replaced by an automatic tape recorder; the positioner is supplemented by an electric synchronous actuator; the direction of displacement of the head during measurement is changed, i.e., the direction is not away from the body surface to the outer edge of the boundary layer, as is customary, but toward it (for which purpose the actuator must have the appropriate direction of rotation). Finally, we eliminate as unnecessary the equipment for recording the instant of contact of the sensor with the body surface. As a result of these changes, the basic setup of the usual equipment is converted into an automatic system (Fig. 1).

In the equipment thus automated, and described here as an example, we used an ordinary head with two psychrometric thermocouples, as developed in [2, 3]. The thermocouples were copper-constantan 0.06 mm in diameter. Moistening of the wet thermocouple was done continuously through the capillary tube of a pipet. An automatic self-balancing strip recorder (KV) was used as recording instrument. The positioner actuator, as in [1], consisted of a synchronous electric motor and reduction gear, capable of a head displacement rate of 0.5 mm/min. The displacement was continuous, and the rate was chosen with regard to the inertia of the thermocouples and the printing frequency of the instrument, so that the thermocouple readings would follow correctly the measured temperatures, while the recorder would in turn record a sufficient number of points to delineate a curve during the time of transit of the thermocouples through the boundary layer. The reversing motor indicated in the diagram had no primary function, but was used to withdraw the thermocouples from the body surface after a measurement was carried out. The double tumbler switch also had no primary function, but was used to turn the head actuator and the strip recorder on and off. Automation of the measurement of thermocouple displacement is based on synchronous operation of the head actuator and the strip recorder. The automatic registration of the time of contact of the thermocouples with the body surface is based on use of the measuring system itself to record the instant of contact.

The system operated as follows: by preliminary rotation of the micrometer screw (manually or with the second, reversing, electric motor) the thermocouples were backed off from the surface and placed in the measuring section at the starting position, at an arbitrary distance from the surface, outside the boundary layer, or close to its outer edge. Then the head actuator and the strip drive in the recorder were switched on. Being set in motion by the synchronous electric motor, the thermocouples passed through the boundary layer toward the body surface, while the recorder automatically registered their readings. The strip charts of the recorders were also set in motion by the synchronous motor. Because the rotation of the electric motor actuators of the head and strip are synchronized through the electric circuit [6], displacement of the strip in the recorder is strictly proportional to displacement of the thermocouples in the boundary layer. Thus, in recording the thermocouple readings, the instrument simultaneously draws to some scale on the moving strip their displacement and corresponding instantaneous positions. Finally, the thermocouples come into contact with the body surface, and remain in that position until the instrument is switched off. This manner of stopping is possible because of some elasticity in

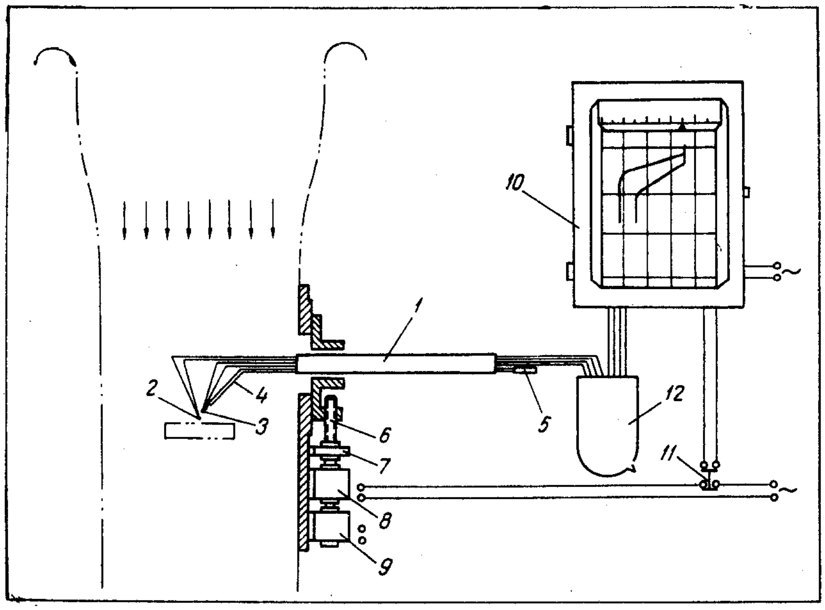

Fig. 1. Scheme for automatic measurement of temperature and humidity fields in the boundary layer: 1) head; 2) dry thermocouple; 3) wet thermocouple; 4) capillary tube; 5) pipet; 6) actuator screw; 7) reduction gear; 8) synchronous electric motor; 9) reversing electric motor; 10) recording potentiometer; 11) double tumbler switch; 12) Dewar flask.

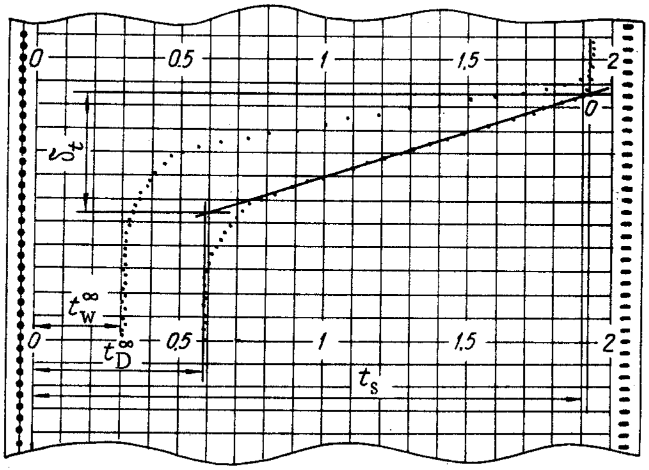

Fig. 2. Samples of automatically drawn graphs of distribution of temperatures of wet and dry thermocouples in the boundary layer: ($u = 12$ m/sec, $t_d^\infty = 16.2°$ C, $t_n^\infty = 8.6°$ C, $t_s = 25.5°$ C, $\delta_t = 0.44$ mm).

their method of attachment to the head. From the time of contact the temperatures of the dry and wet thermocouples become equal and remain unchanged. Accordingly, the time of contact is indicated by an initial section of constant temperature on the diagrams. The result of this scheme of operation, in which the readings, displacements, and thermocouple contacts with the body surface are automatically recorded, is that the strip bears diagrams of the temperature fields of the wet and dry thermocouples. The graphical representation of the boundary layer (Fig. 2) is magnified according to the number of times the speed of the strip is greater than that of the thermocouples.

The graphs obtained may be worked on directly on the strip to determine boundary layer thickness. For this purpose, a convenient slope and scale may be assigned to the graphs, by preliminary choice of limits of measurement of the recorder and velocities of the strip and thermocouples. The scale is determined as the ratio of the design strip rate indicated in the instrument certificate to the rate of displacement of the positioner, which in turn is determined as the product of the screw pitch and the calculated number of revolutions. When there are frequency fluctuations in the electric circuit, the rate of traverse of the sensor and strip will differ from the calculated values, but the scale of the record, being the ratio of the velocities, remains unchanged. If the instrument scale is uniform and is marked off in degrees, the conventional thickness of the thermal boundary layer is determined by the usual graphical method directly on the strip. This is possible when the temperature drop in the boundary layer is small, and the dependence of the thermocouple emf on temperature may be considered linear. The point where the boundary layer starts (for a temperature graph, for example, of the dry thermocouple, this is point 0 in Fig. 2) may be determined from the time noted on the diagram when each thermocouple makes contact with the body surface (adding the thermocouple radius). Using a second method, this point lies on the intersection of the straight-line sections of the diagram which characterize the temperatures of the beginning of the boundary layer and the body surface. The latter method is convenient to use in investigating a boundary layer above a free liquid surface, when, because of wetting and the good thermal contact with the liquid, the thermocouple readings are close to the temperature of the evaporation surface. The method is also convenient in cases when the body surface temperature is recorded on the strip by means of a supplementary thermocouple embedded in the surface.

The equipment described as an example is used in a vertical wind tunnel. The mechanism for drawing on the recording potentiometer strip allows stepwise choice of its rate of motion. The maximum rate is 60 mm/min, when the boundary layer picture is magnified 120 times on the strip. The time required to measure the temperature and humidity fields in a single section of the boundary layer is 1–1. 5 min, during which time up to 50 readings of each thermocouple are recorded.

Recording of the readings of each thermocouple separately permits simplified installation of thermocouples on the head, since it relaxes the requirement for simultaneous mounting of the dry and wet thermocouples in a single plane parallel to the body surface. In all the other methods described this was necessary. The thermocouples may be arbitrarily moved one relative to the other in the direction of the body surface, as indicated in the diagram (Fig. 1). Such a movement causes a corresponding displacement on the strip of the dry thermocouple graph relative to the wet thermocouple graph (see Fig. 2). This is actually desirable, since, though it does not influence the nature of the graphs themselves, it enables superposition of the graphs to be avoided. It is convenient to have independent elastic means of fastening the thermocouples to the head, to permit a thermocouple to fold back after contact with the surface, and not to resist the motion of the second thermocouple.

When there is a need for simultaneous measurement in several sections of the boundary layer, the scheme allows simultaneous use of any number of twin and single thermocouples in combination with any number of heads, actuators, and recorders. Simultaneous measurement of any combination will be achieved by synchronous operation of the actuator motors of all the heads and recorder strip charts.

It is clear that we may use in the system any other quick-response temperature and humidity sensors suitable for measurement in small volumes, and the appropriate recorders. Moreover, having the sensors and recorders, we can similarly automate measurement of any parameter, for example, velocity and pressure in the boundary layer, in channels or other flows.

The method described for automating measurements and drawing graphs, and also the elastic sensor mounts, do not introduce any major changes in the measuring system ordinarily used. Therefore the limits of application of equipment automated in this way, and their measurement errors remain the same as for equipment of the ordinary kind, as described in [2–5]. The accuracy of the graphs drawn increases because of the rapid recording of a large number of readings.

At the present time we have automated, on the basis of the several variants of the method described, all the experimental equipment relating to heat and mass transfer, in natural and forced convection, used in the Heat and Mass Transfer Laboratory of the Institute of Building Physics, where more detailed information on this matter may be obtained.

NOTATION

u – velocity of oncoming air stream; t_d^∞ – stream temperature from readings of dry thermocouple; t_w^∞ – stream temperature from readings of wet thermocouple; t_s – temperature of evaporation surface; δ_t – conventional thickness of thermal boundary layer.

REFERENCES

1. B. M. Smol'skii, External Heat and Mass Transfer in Convective Drying [in Russian], BGU, Minsk, 1957.
2. N. F. Dokuchaev, Use of Thermal Hygrometric Methods to Investigate Evaporation Processes, Dissertation, MTIPP, 1951.
3. A. V. Nesterenko, Experimental Investigation of Heat and Mass Transfer Processes in Evaporation of a Liquid from a Free Surface, Dissertation, MIIGS, 1953.
4. N. S. Mikheeva, Tr. MTIPP, no. 6, Pishchepromizdat, 1956.
5. I. S. Mel'nikova, Research in Building Heat Technology and Climatology [in Russian], Gosstroiizdat, 1962.
6. A. S. Kasatkin and M. A. Perekalin, Electrical Engineering [in Russian], Gosenergoizdat, 1961.

8 August 1965

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