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# TRANSLATION

ON STATIONARY METEOROLOGICAL MEASUREMENTS IN LOWER 300-METER LAYER OF THE ATMOSPHERE

By

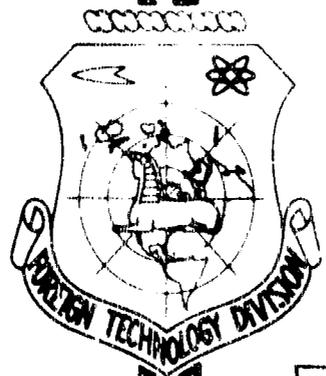
F. Ya. Klinov

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# **EDITED MACHINE TRANSLATION**

**ON STATIONARY METEOROLOGICAL MEASUREMENTS IN LOWER 300-METER  
LAYER OF THE ATMOSPHERE**

**BY: F. Ya. Klinov**

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ON STATIONARY METEOROLOGICAL MEASUREMENTS IN LOWER  
300-METER LAYER OF THE ATMOSPHERE

F. Ya. Klinov

Introduction

The solution of practical problems associated with processes of mixing and transport of impurities in the lower layer of atmosphere, and the study of complex meteorological processes are possible only with a stable system of automatic meteorological measurements during the entire layer. For such investigations lately there have been used lofty, chiefly radio- and television, mast and special meteorological towers. Such structures, equipped by a complex of measuring apparatus, serve like a probe, thrust into an atmospheric layer.

At the Institute of Applied Geophysics on the initiative of Acad. Ye. K. Fedorov and in conformity with its base installations there has been developed and partially introduced into operation a complex of automatic meteorological measurements in the lower 300-meter layer of atmosphere. This, essentially, is an automatic geophysical observatory (AGO), which has been based on the high tower of the Institute.

The tower with a height of 310 m — is a tubular mast (Fig. 1) of uniform diameter, equal to 2.4 m over its entire height. The upper level of measurements is higher as the result of an extension type vertical pole which can be raised to 315 meters.

The selection of such type of mast is stipulated by the simplicity and strength of its construction, technical possibilities of communication between its operating levels (elevator), the reliability of wiring of power and telemetering lines inside mast and their shielding from external electromagnetic fields of industrial and natural origin, the homogeneity of conditions of flow around the tower by the air.

The mast is made of butt-welded steel frames 6 m in length. Its frame is supported on spherical base and reinforced by four gradations of steel cables (guy), pulled downwards from levels of tower 72.7; 144.9; 217.1; 289.2 m to a distance of 75—150 m from its base. From the first three of these levels of tower to the guys there are stretched horizontally guard ropes onto which are suspended carriages for radial mobile measurements at a distance up to 40 m from the tower.

In addition to the operating point at the top of the extension (type) vertical pole (315 m), and the upper platform (310 m), there are 13 platforms (balconies) around tower at levels of 24.6; 48.7; 72.7; 96.8; 120.8; 144.9; 169.0; 193.0; 217.1; 241.1; 265.2; 289.2; and 301.2 m. The width of balconies is 1.0 to 1.5 m.

From balconies, the 6-meter extension rods are moved out to the west, north, east, and south, at their ends are mounted measuring instruments; sensors of temperature, speed and direction of wind, and also strain-gauge sensors of the microoscillations or pulsations of the wind speed (Fig. 2).

For special investigations on top of tower there is a workers office, 4-meter in diameter 3-meters high with window port-holes. Descent and ascent are made by an elevator. The power and telemetering lines are strung inside tower and at its foundations are led into recorder room, whence there is realized the centralized switching and monitoring of the telemetering meteorological apparatus.

The tower under effect of wind loads experiences complex oscillations (Fig. 3). In investigations, carried out by M. P. Barshteyn, P. K. Shklovskiy and A. S. Arkhipov, in a range of wind speed up to 10 m/sec two types of mast oscillations have been established with a frequency  $\nu = 0.40$  c/s, corresponding to one of forms

of oscillations of system of masses, concentrated at joints of the tower, and with frequency  $\nu = 0.80$  c/s, corresponding to oscillations of tower as an elastic rod on a solid support.

In random processes of oscillations of tower there have been recorded virtually periodic components. For example, for upper point of tower (310 m) the basic frequency of the virtually periodic component is equal to 0.80 c/s; the predominant frequency of a purely random process is 0.40 c/s. On the guy ropes of the two upper levels a frequency of 0.22 to 0.28 c/s has been recorded. As a rule, the trunk of the tower oscillates in direction of wind and perpendicular to it with a frequency 0.76 to 0.86 c/s.

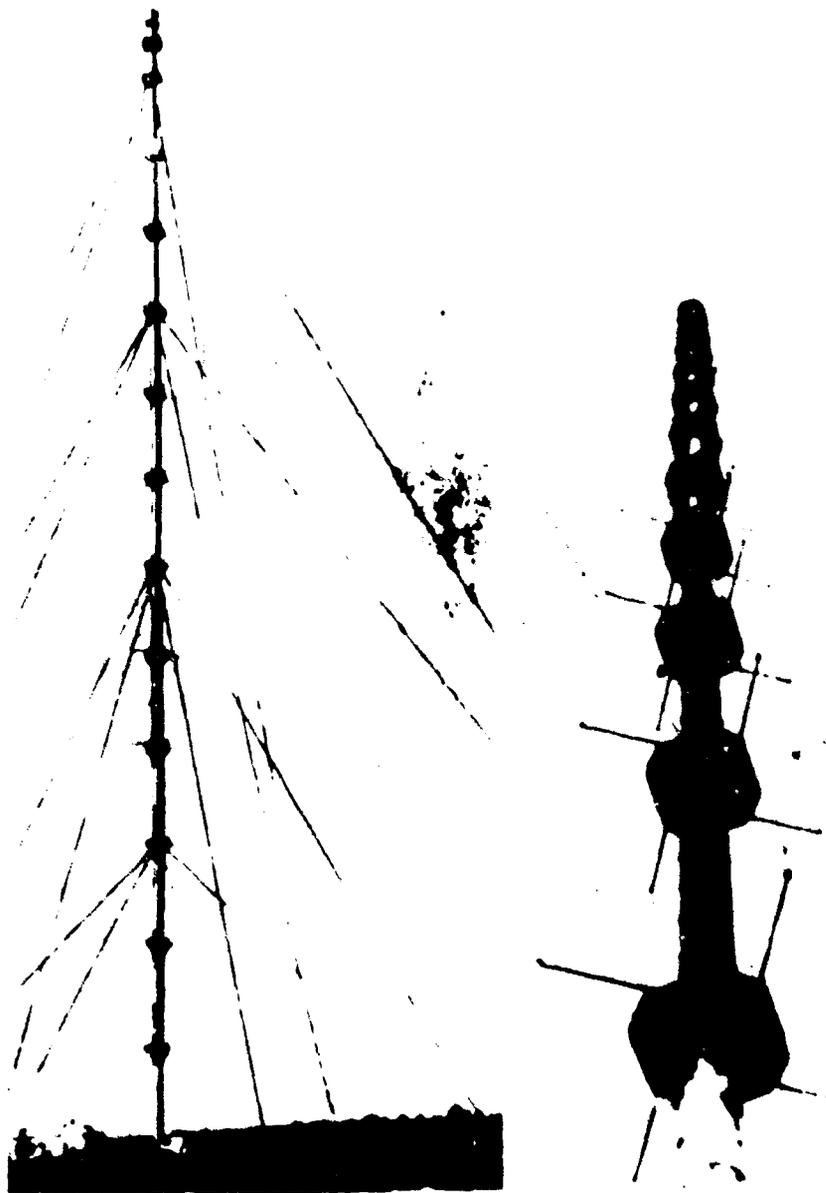


Fig. 1. General view of high tower.



Fig. 2. Operating extension rods with mounted sensing units.

Joints of the tower (places of guy-reinforcements) basically oscillate with a frequency of 0.40 to 0.46 c/s; there have been also recorded oscillations of these points in a direction, perpendicular to the direction of wind with a frequency of 1.20 to 1.35 c/s.

If we assume the oscillations of the tower are realized by its sinusoidal law, then its displacement can be presented in the form of

$$x = A \sin \omega t,$$

where  $A$  is the maximum displacement of tower trunk;

$\omega$  is the cyclic frequency; hence the maximum rate of displacement of point of tower trunk is expressed as:

$$(dx/dt)_{\max} = A\omega = 2\pi Af.$$

The amplitude of tower trunk displacement of 0.3 to 4.0 mm has been observed with a wind speed up to 10 m/sec and the chief maximum frequencies are 0.76 to 0.86 c/s.

Hence the maximum rate of the tower displacement will be equal to

$$(dx/dt)_{\max} = 2\pi \cdot 0.004 \cdot 0.86 = 0.022 \text{ m sec.}$$

which is much lower than the threshold of sensitivity of wind speed sensor equal to 0.5 m/sec.

The high tower (Fig. 4) has been constructed in a clearing. From the south

at distance up to 300 m a deciduous forest approaches the clearing. On the east and north, the clearing and adjacent meadow with groups of trees and thickets extend for a distance 1.0—2.0 km, farther on a continuous forest begins. From the west towards clearing there adjoins a built-up section and farther at a distance of more than 1.5 km is a forest which descends into a ravine, beyond which there flows a river. At the very base of tower and near it at a distance of 100 to 200 m are service buildings, separate thickets and group of trees. The clearing is encircled by standard solid fence and is covered with a stand of perennial grass. From tower



Fig. 3. Schematic diagram of oscillations of tower (dotted line) in relative magnitudes. By the points there are designated places of guy-reinforcement (point of joint), figure near them is the height above surface of ground in m; a — profile of oscillations; b — axis of tower.

to the nearby highway is a concrete road. The described conditions on the surface, concrete road and certain service sites stipulate a macroroughness which creates a thermal heterogeneity in the area near the tower.

The developed complex of automatic geophysical observatory (AGO) includes (Fig. 5) introduction of gradient and structural measurements of meteorological and radiation characteristics on high-tower (in the layer 2—315 m), and also the measurement of temperature, speed and direction of wind, humidity on a gradient mast (2 to 30 m) et al.

Guidance in developing the complex (AGO) were determined by experiments of USSR and foreign investigations made on masts and towers [30].

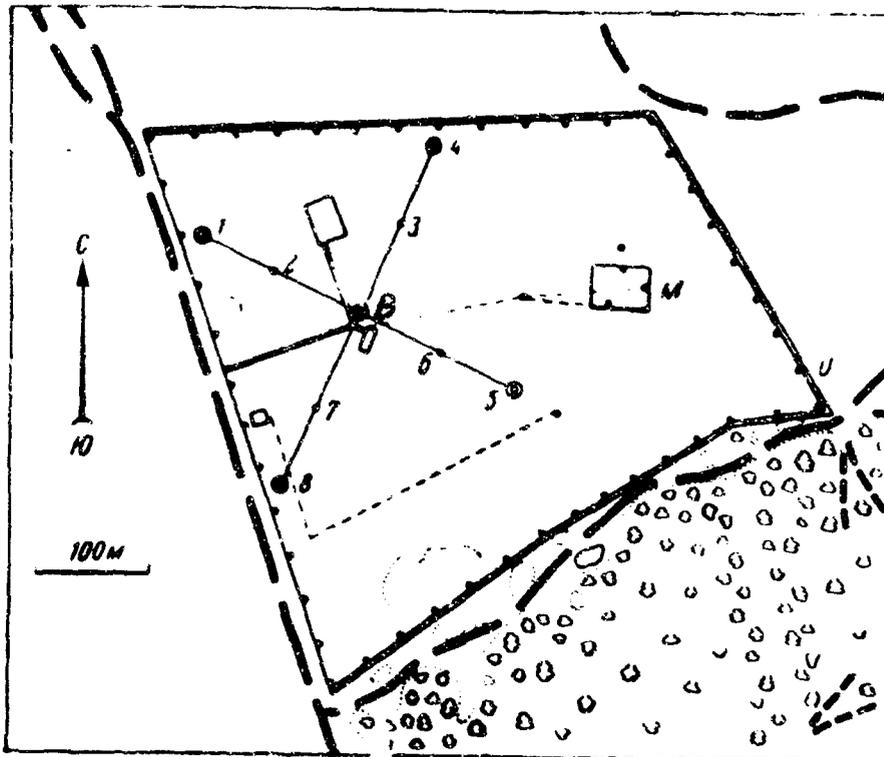


Fig. 4. Plan-diagram of microregion, near tower.  
 B — tower; M — Meteorological Platform; 1—8—  
 —guy ropes.

In the adopted methods of measurement of speed of wind on towers and masts [67, 74, 75, 82, 89, 94] there are used Feuss anemometers, cup anemometers with electro-mechanical contact-pulse output and transmitting sensors. Registration of speed of wind is realized at same time from the pulse and transmitting sensing elements of the cup and propeller type to a relay register-recorder, and also by potentiometric circuit. Accuracy of measurement will attain 0.2 to 0.5 m/sec.

Direction of wind is measured by sensors with a rheostat converter by a bridge circuit and with selsyn follower for angular displacement of indicator of direction [68, 69 et al]. For measuring the wind direction there are used in addition to standard weather vanes and wind cones two-dimensional weather vanes (double vane [62, 75, 80, 88]. At the same time, the follower of recorder on vertical and horizontal deviations of the double vane is realized by a selsyn connection. The attained accuracy of the measurement of wind direction is 2 to 5°.

Measurements of temperature are made [61, 64, 67—69, 89] with mercurial

thermometers, copper resistance thermometers and electropsychrometers with copper and platinum resistance thermometers, and also thermocouples with amplifying of signals of sensor units. The recording is realized by bridges or potentiometric circuits. The attained accuracy of measurement of temperature is  $0.1^{\circ}\text{C}$ . The accuracy of direct measurements of temperature gradients is in hundredths of a degree.

The humidity is measured by hygrometers with registration on potentiometer, semiconductor psychrometers, electropsychrometers et al. [61, 62, 67, 80, 81]. The accuracy of measurements is  $\pm 3\%$ . In measurements on towers and masts there is some experience in registering radiation characteristics from standard sensor units on electronic potentiometers.

For measurement of pulsations of temperature, speed and direction of wind in Soviet and foreign investigations there are used a different type of micro-thermometers, hot-wire and strain-gauge anemometers acoustical thermometers, and anemometers with registration on electronic recording instruments, oscillographs, etc. [5, 6, 15, 16, 25, 35, 39, 42, 54, 57-60]. The constant of time of pulsation thermometers described in literature is 0.01 sec and of pulsation anemometers — 0.01 to 0.1 sec. The accuracy of measurement of temperature pulsations is  $0.01^{\circ}$  of pulsations of wind speed — several m/sec and of pulsation of direction of wind — 1 to 3% of scale of measurements.

The distribution of instruments on towers and masts according to this or another scheme of the distribution by height of meteorological parameters cannot be justified in view of theoretical diversity of these schemes, their association with the thermal stratification, dynamic conditions, distribution of humidity et al. [7, 71, 85]. Schemes of distribution of meteorological parameters in the lower layer of atmosphere (near 100 m and higher) are indeterminate and appropriate theoretical and experimental investigations are rare. This explains the variety of selection of levels of the distribution of sensing elements on towers and masts

[14, 67, 69, 72, 76, 78, 82, 85, 86, 89]. Usually in investigations in the lower layer of atmosphere they are assumed by proceeding from engineering possibilities of a high structure; insofar as possible the sensor units are placed at levels corresponding to any one scheme of the meteorological parameters aloft adopted by any one investigator.

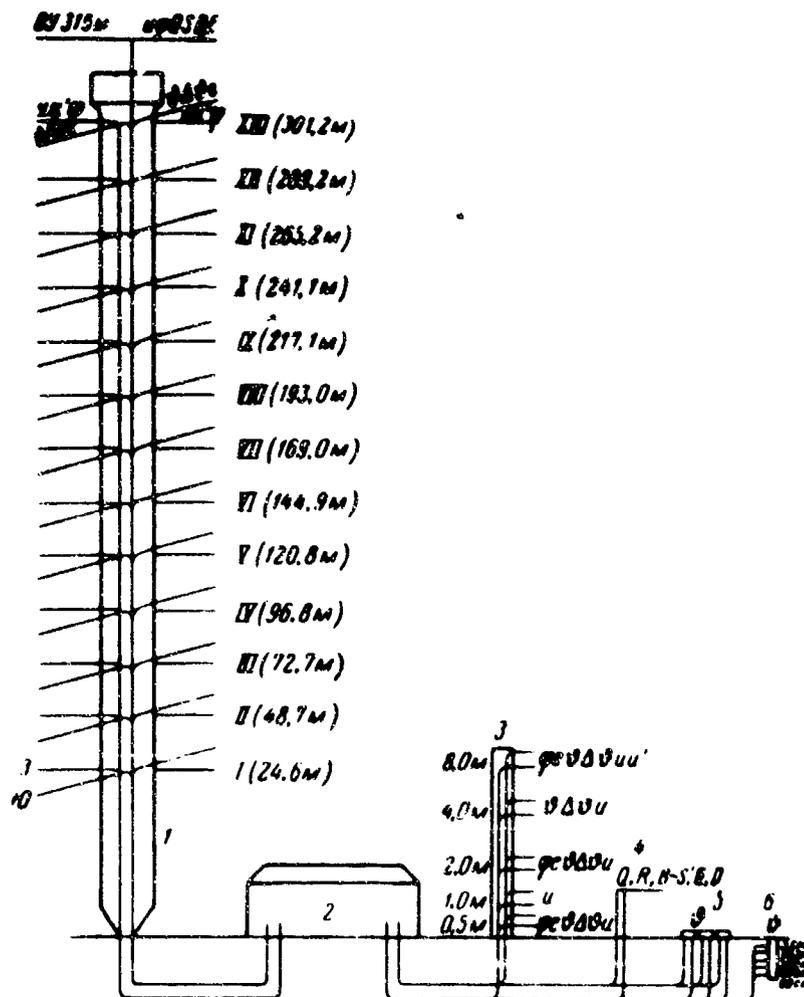


Fig. 5. Schematic diagram of complex of automatic meteorological measurements on high tower.

1—Tower; 2—Recorder; 3—Gradient mast; 4—Radiation measurements; 5—Measurements in soil.

Below are presented the chief principles and certain bases of the adopted schemes of measurements made on high towers.

## 1. GRADIENT MEASUREMENTS

### Measurement of Average Wind Speed

Measurement of the average wind speed on a high-tower is realized by a

telemetering photopulse anemograph, schematic circuit and operating model of which L. G. Kachurin, B. Ya. Tolstobrov, N. S. Yalynichev and V. M. Ushakov [27] developed.

The circuit of the photopulse anemograph (Fig. 6) includes a noncontact photopulse sensing unit, an electronic decoding (scalar) mechanism and relay recorder-marker of the pulses.

Photopulse sensing unit is a three-cup vane onto the lower end of whose shaft there is attached a disk with an aperture. Above disk there is fastened an illuminator, under it a — hermetically sealed photoconductive cell connected to the equilibrium bridge of the sensing unit. In rotating the vane under the action of wind load at the moment of its alignment with illuminator, apertures in the disk and photoresistor in the latter during its illumination as the result of photoconductive effect, the resistance decreases. In this case there occurs a modulation of illumination of the operating surface of the photoresistor with the number of turns of cup vane. The conductance of the photoresistor under action of luminous flux increases. The current, passing through photoresistor, is a function of the luminous flux.

In rotating the disk of the photopulse sensing unit the illumination of photoresistor is modulated and in its circuit there flows a pulsating current, frequency of the pulsation ( $f_g$ ) of which is determined by number of apertures  $k$  in the disk (in our case  $k = 1$ ) and number of rotations of the disk per minute:

$$f_g = \frac{n}{60} k.$$

Application in this case of a photoresistor which is the most sensitive and the least bulky photoconverter, makes it possible (in distinction, for example, from circuit with photocell) to simplify the receiving circuit diagram with a more powerful signal. The applied photoresistor (FSA-01) possesses high sensitivity in voltage and little inertia. The inertia of the photoresistor (up to 0.005 sec) abruptly lowers current at higher frequencies.

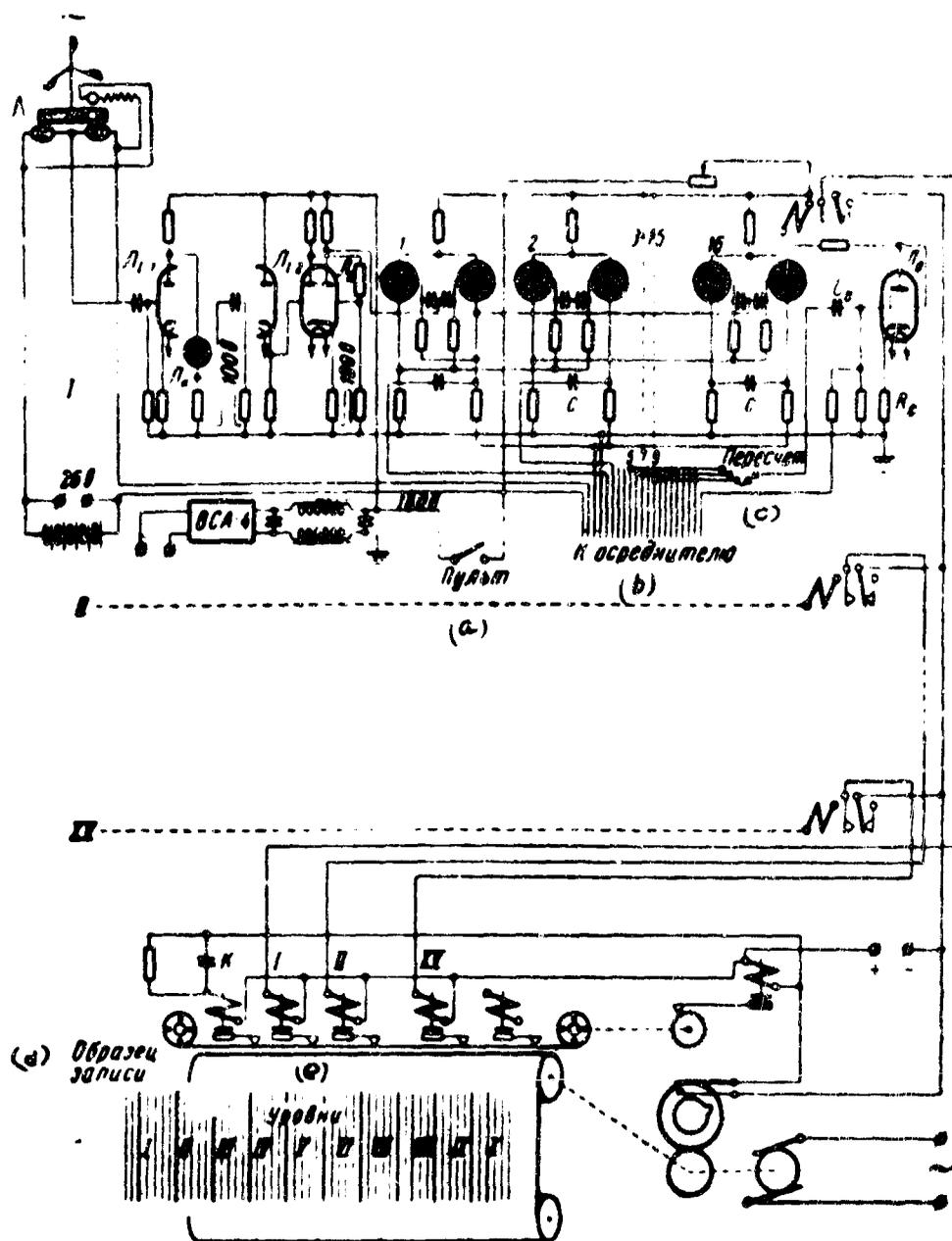


Fig. 6. Fundamental circuit of photopulse anemograph (measuring and registering unit); I—V levels.  
 KEY: (a) Panel; (b) To averager; (c) Coding device; (d) Specimen of recording; (e) Levels.

As the coefficient of the inertia of photopulse anemograph vane there has been adopted the time of its establishment or of the synchronisation  $\tau$ , equal to an interval of time during which the initial difference between the speeds of the sensing unit and of the flow itself varies by  $e$  times. The path of the synchronisation of the vane  $L = V\tau$  corresponds to the time of synchronisation of the wind

speed sensing unit. It may be determined from expression [24]:

$$U - V = (U_0 - V) e^{-\frac{V\tau}{L}},$$

where  $U$  is the reading of the anemometer (linear speed of vane) and  $U_0 = (U) = 0$ .

Path of synchronization of cup vane is assumed equal to several tens of meters.

The period of averaging  $p$  of wind speed greater exceeds the time of synchronization  $\tau \ll p$ .

In the design and operating circuit of photopulse anemograph, V. V. Poltavskiy, V. N. Ivanov, and the author introduced a number of changes. Thus, electronic decoding device, instead of individual unit for each sensing unit has been combined into one panel. The separate power supply of the decoding bars which have complicated the circuit and have been the source of additional interferences, has been replaced by a common external circuit of power supply of entire decoding mechanism from a universal power source. There is realized a separate power supply of anode circuit of the forming cascade and unit of binary cells.

This is caused by the fact that the oscillation of power supply voltage in the forming cascade during unlocking and cutoff of its tubes is inadmissible at the level of unit of binary cells in the anode circuits. The variable component which proceeds to the anode of block of binary cells is extinguished by the resistance at the entry point of anode.

In an operating circuit the power supply of the sensing element is separated from the circuit of the decoding devices; the input is modified: the pulse shaper (neon tube) is disconnected from regulating input cathode resistor  $L_1$  and connected to anode  $L_1$ . At entry of first triode there is introduced a grid separation condenser with the resistance of leakage which stabilizes the regime of first tube, since to it there does not apply the constant component proceeding from photo-resistor of the sensing element. Actually the adjustment of voltage for the illuminator becomes unnecessary. Illuminator in the operating circuit works in wide range of voltages (12—26 v).

The registration of a moderate wind speed is realized by the pulse marks that is by the point method — according to the number of points or marks of respective pulses per unit of time (per unit length of the recording tape). The selection of such a type of records is stipulated by the simplicity of its design, manufacture and utilization and by the possibility of synchronous (composite) registrations on the basis of the point marks made from several sensing elements (at various levels).

In addition, with a change in the rate of unwinding of recording tape it is possible to alter the "sensitivity" of the registration (to alter the number of points per unit length of recording tape or graph).

The range of measurement of wind speed by a photopulse anemograph (from 0.3 to 40 m/sec) from below is limited by the sensitivity of the sensing units and its limit corresponds to the possible maximum wind speed in the vicinity of the high tower.

Errors of measurement of the described circuits, are determined by the dispersion of points from the straight line  $n = f(U)$ , at  $U \leq 10$  m/sec constitute  $\leq \pm 0.3$  m/sec; at  $U \leq 20$  m/sec —  $\leq \pm 0.5$  m/sec; at  $U \leq 40$  m/sec —  $\leq \pm 1.0$  m/sec.

From a series of more than 300 measurements with ten-minute interval averagings made by Yu. A. Kurpakov et al. with the sensing units of photopulse anemograph, operating on tower it is found that all measurements, presented in relative values  $\frac{\Delta n}{n}$ , where  $n$  is the total number of ten-minute series of measurements  $\Delta n$  is the number of series, during the corresponding interval which must be errors of measurement of wind speed are contained in  $\pm 5\%$  of errors of measurement of wind speed  $\frac{\Delta U}{U}$ , where  $\Delta U$  is deviation of values of wind speed according to measurements by individual sensing units from average speed of wind  $U$ , determined by the readings of a group of sensing units (Fig. 7). The indicated errors  $(\frac{\Delta U}{U})$  depending on wind speed do not go beyond the limit of 5% near threshold of sensitivity of sensing unit and constitute less than 2% during wind speeds of more than 2 m/sec (Fig. 8).

The chief merits of the adopted scheme of photopulse anemograph are: a) stability of the calibration curves and small threshold of sensitivity (0.3—0.5 m/sec); b) absence of unreliable and unstable electromechanical relays and electromagnetic high-resolution counters over a long period of operation; c) application of electronic reduction of pulses of sensing units which makes it possible in wide range to alter their sensitivity; it is possible also to alter the "sensitivity" of the recording (to vary the number of points per unit of length of recording tape or trace) with a change in rate of unrolling the tape (or trace paper); d) the possibility of a synchronous and composite recording of wind speed on relay recorder on the principle of point marks from all levels of the layer of atmosphere under investigation.

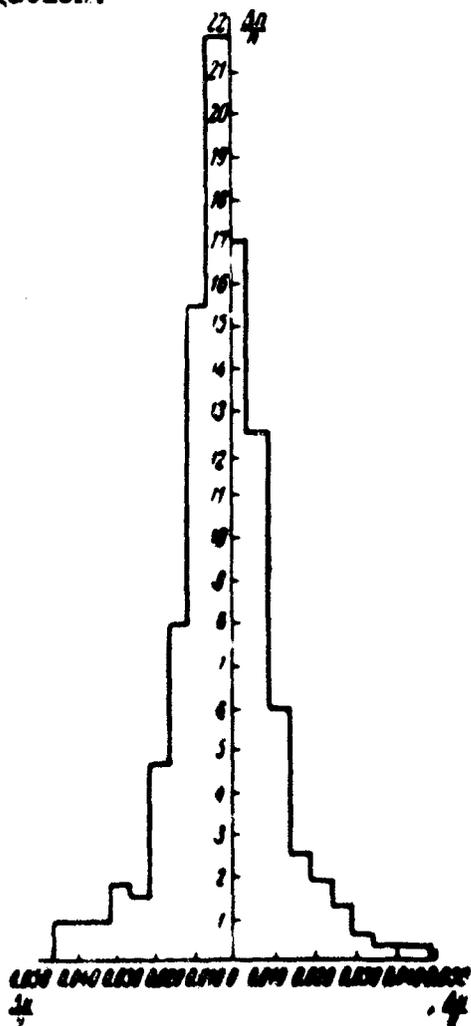


Fig. 7. Relationship between the relative number ten-minute series of measurements  $\frac{\Delta n}{n}$  and relative errors of measurement of speed of wind  $\pm \frac{\Delta U}{U}$ .

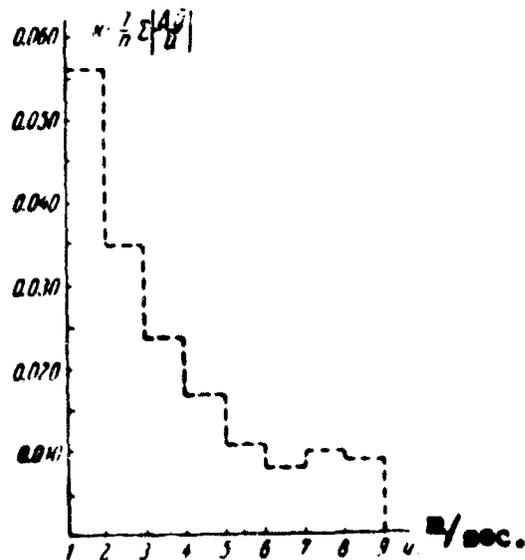


Fig. 8. Dependence of errors of measurement of wind speed  $\frac{\Delta U}{U}$  on value of wind speed (U).

#### Measurement of Wind Direction

Measurement and registration of wind direction are made in the complex of the high tower by scheme of one-dimensional rhumbograph. An operating one-dimensional

rhumbograph consists of receiver, the sensitive element of which, according to S. T. Mashkova's idea is a compass-card adopted with converter rheochord ( $R = 19 \text{ ohm}$ ), and recorder a single-channel recorder MS-103.

As the basis of the operation of circuit there is placed the bridge (zero) method of measuring the resistance of rheochord, which is found in a definite dependence on the angular mounting of the compass card. Fundamental circuit of one-dimensional rhumbograph (Fig. 9) is a single automatic balanced bridge of resistances, to one of arms of which is connected the operating rheochord-converter. In this circuit there is included a thermocompensation of the leads.

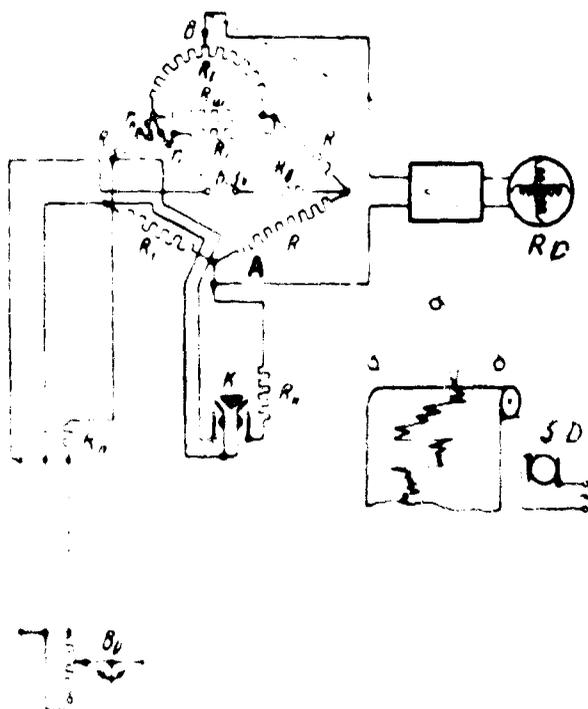


Fig. 9. Fundamental circuit of one-dimensional "rhumbograph".

In the circuit the following designations have been adopted.  $B_p$  is converter of sensing unit of wind direction;  $R_1, R_2, R_3, R_0$  are the resistances of arms of bridge;  $R_s$  is the resistance, employed for limiting the current of measuring circuit;  $R_{II}$  is the shunt of rheochord for adjusting its resistance to the standard magnitude 90 cm;  $R_{II}$  is the resistance for adjusting the resistance of rheochord to a magnitude, corresponding given limit of the measurement;  $r_0, r_{II}$  are resistances for adjusting the limit of measurement of instrument.

With a change in mounting the compass card this also means positions of contact rheochord, change and its resistance  $B_p$  varies; here there is disturbed the equilibrium of the point. In measuring diagonal AB of the bridge there appears a voltage, which is strengthened by electronic amplifier to a magnitude, sufficient for activating a reversible motor. Rotor of motor, in being rotated, shifts the slide B along the rheochord up to moment of occurrence of bridge equilibrium. By a transmitting system with rheochord slide the carriage of recording instrument is connected with the pen. Simultaneously with a shifting of the slide along the rheochord along a scale, graduated in angular degrees from 0 to 360°, the indicator shifts with the pen of the carriage. For each magnitude of the mounting of compass-card there corresponds a definite value of resistance of rheochord and consequently also a definite position of the rheochord slide and the indicator and pen of carriage connected with it; the pen traces on the diagrammed tape a curve of change of mounting of compass-card. The unwinding of the diagrammed tape is realized by the synchronous motor SD of the recording instrument.

Control of adjustment of instrument (by operating current) is realized by short-circuiting of line of converters by pushbutton K with simultaneous shunting of arm with a resistance  $R_k$ , selected in such a way that the indicator of instrument here is set at the initial mark of scale.

The accuracy of measurement of wind direction in the scheme of a one-dimensional rhumbograph is 5 to 10°. For registration of two-dimensional measurement of wind direction Ye. I. Tsitsurin, M. G. Faynshteyn, the author et al. developed a birhumbograph circuit.

Fundamental circuit of a birhumbograph (Fig. 10) consists of two-dimensional sensing unit direction (double vane), selsyn tracking circuit, realized in transformer method with amplifying, feedback circuits, a converter for  $f = 400$  c/s, a unit with power supply and recorder combined with recording trace of wind direction component.

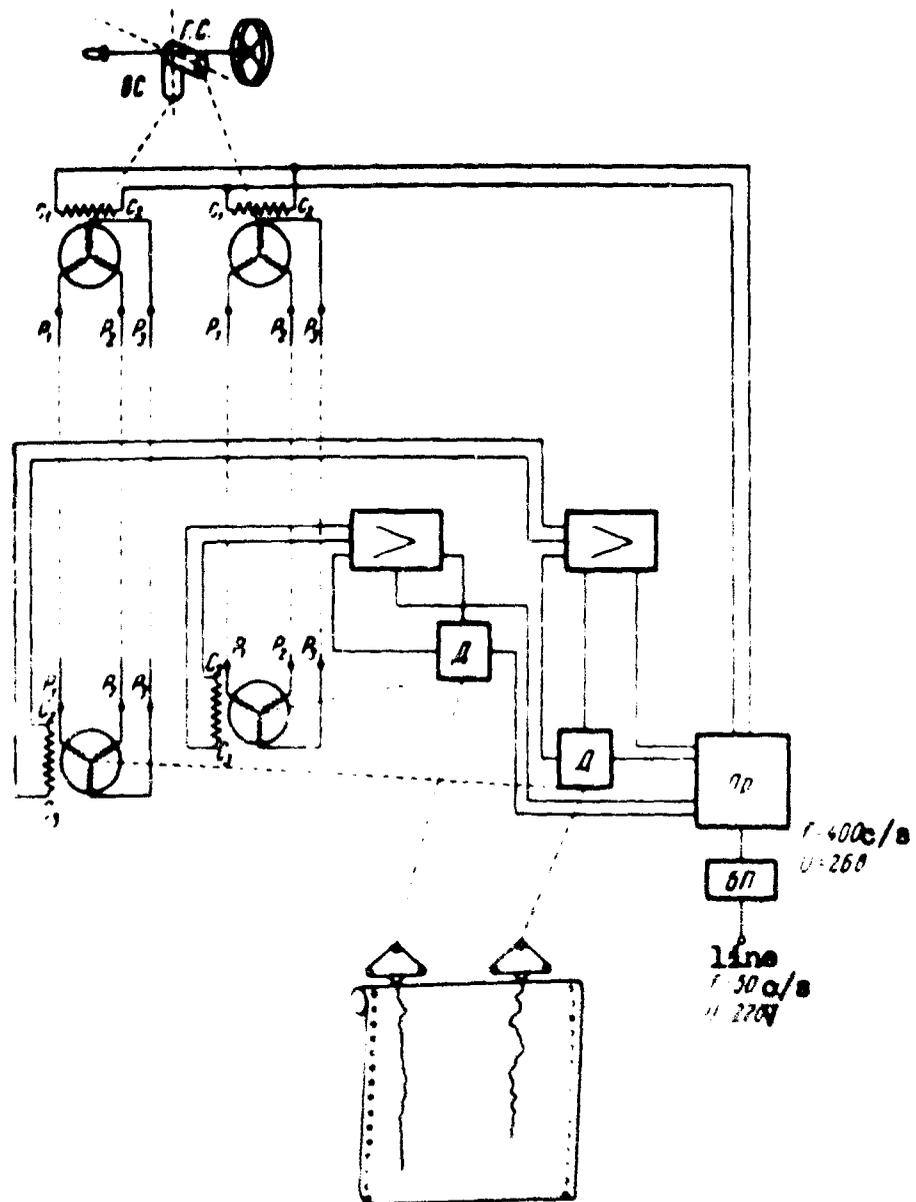


Fig. 10. Fundamental circuit "birkumbograph" (measuring and recording block).

БП — Power supply unit; Пр — converter; Д — slide; > — amplifier;  $P_1, P_2, P_3$  — phase windings;  $C_1, C_2, C_3$  — excitation windings.

The sensing unit of two-dimensional wind direction — the double vane is a balanced rod with annular stabiliser, freely oscillating around center of equilibrium in vertical and horizontal planes.

Fixation of position of double vane realized by selsyn connection, makes it possible to determine the horizontal and vertical angles of vector of speed and by the known values of angles and of speed  $V$  to calculate the components of the speed.

Longitudinal:

$$u = V \cos \alpha \cos \beta,$$

transverse:

$$v = V \cos \beta \sin \alpha,$$

vertical:

$$w = V \sin \beta.$$

Here  $\alpha$  is the deviation of horizontal component of speed vector of flow from the direction, taken in the horizontal plane for the longitudinal;  $\beta$  is the angle between vector  $V$  and the horizontal plane

$$V = \frac{\sqrt{u^2 + v^2}}{\cos \beta}.$$

The magnitude of horizontal vector  $\sqrt{u^2 + v^2}$  is determined by an anemometer.

Vertical movement of the double vane is limited to angles of  $\pm 40^\circ$  (with an accuracy of 3 to 5°), which are the practically observable maximum deviations of the flow from horizontal (including deviation along vertical from balanced position by 2 to 3° and the displacing of selsyn-sensing units and selsyn-receivers by 1 to 2°). Its horizontal displacement is assumed to be within the limits of 0—360°.

Coefficients of attenuation of the horizontal and vertical movement of double vane with annular stabilizer can be determined from empirical expressions [79]:

$\lambda_s = a_s U$ ;  $\lambda_r = a_r U$ . The period of attenuation (in sec) will be expressed as:  $T = K/U$ . The constants  $a_s$ ,  $a_r$  and  $K$  are determined from experience.

If the movement of the double vane in the flow is described by the expression

$$\theta = \theta_0 e^{-\lambda t} \cos \frac{2\pi}{T} t, \text{ then for the vertical and horizontal movements of double}$$

vane the corresponding expressions are presented in the form of

$$\begin{aligned} \theta_{\text{ver}} &= \theta_0 e^{-a_s U t} \cos \frac{2\pi}{T} t. \\ \theta_{\text{hor}} &= \theta_0 e^{-a_r U t} \cos \frac{2\pi}{T} t. \end{aligned}$$

Forces, adequate for surmounting friction and forces restoring neutral position of double vane in flow during its deviation generate with a wind speed of 0.3—0.5 m/sec. This wind speed is the threshold for a "birhumbograph". For each of the directions there is a follow-up system.

As recorder there is used a miniature bridge of type MS-1, in which there is mounted two selsyn-receivers, follow-up systems of vertical and horizontal deviations of the double vanes, corresponding amplifiers, reversible motors and a converter common for both circuits.

The recording trace of the horizontal and vertical deviations of the double vane is realized synchronously and combined on one tape.

The rate of unwinding of tape in recorder depending on the adopted averaging of double vane deviations on recording trace and the resolvability of signal marks on the tape can be established from 120 to 5000 mm/hr.

The chief merits of the devised "birhumbograph" circuit are the two-dimensional registration of the wind speed, the low threshold wind speed of —0.3—0.5 m/sec, application of follow-up system with mag-slips, a synchronous and composite recording trace of the measurements on recording instrument.

#### Measurement of Average Temperature and Difference Between (Gradients) Temperatures in the Layer

Measurement and registration of temperature and the difference (gradients) between temperatures in the layer is realized by an automatic remote-control "thermogradientograph", the fundamental circuit and operating model of which L. G. Kachurin, B. Ya. Tolstobrov, N. S. Yalynichev and V. M. Ushakov [28] developed.

The circuit of the thermogradientograph (Fig. 11) consists of sensing units, the sensitive elements of which are resistance copper thermometers ( $R = 220 \text{ ohm}$ ), a relay switch of series connections of differential and complex bridges, composed of thermistors, and a multipoint indicator of equilibrium (recorder), onto which the corresponding voltages of the unbalance are given.

In the adopted sensing unit with a nonframed resistance copper thermometer there is eliminated the tensometric effect, by which there is attained a great stability of its calibration curve.

Coefficient of thermal inertia of sensing unit in the circuit of the "thermogradientograph" amounts to  $\lambda \approx 48$  sec. Significantly lesser time constant ( $\lambda = 1-2$  sec) is possessed by thermoelectric converter -- thermocouple, the use of which thin wires virtually excludes the radiation error, but greatly complicates the circuit of amplifying of signals, especially during their transmission at great distances.

It must be borne in mind [14], that the temperature of surface of the cap of resistance thermometer over its length varies, its minimum deviation from the readings of standard thermometer is recorded in middle of the cap of resistance thermometer and increases to point of bracing of resistance thermometer in sensing unit and the outlet leads in the external circuit.

Radiation balance of surface of the sensitive element of sensing unit reduces to a minimum owing to the introduced in its design double, and then triple radiation shields and owing to the aspiration of air between sensitive element and internal shield of sensing unit, and also internal and external shielding conducts. To this (maximum reflection of solar and thermal beams) there corresponds the polishing (nickel-plating) of the shielded surface of sensitive elements.

The recorder in the scheme of the "thermogradientograph" represents an electronic recording instrument EPP-09M1 with a scheme for recording one-half of the sum of temperatures at upper and lower limits of the layer (half-sums) (average temperature of layer between operating levels of tower) and difference between the temperatures at upper and lower limits of these layers. The recording is realized by the ordinate method (on an ordinate, read off from an independent base line, there is determined the nominal value of parameter).

The entire measurement cycle of the half-sums and differences between

temperatures in the entire layer from 2 to 315 m, i.e., interval of time between recorder marks of one and the same parameter by the printing mechanism of the recorder, is realized in a period of two minutes. Depending upon the range of measurements the sensitivity during recording of the temperature amounts to 6 to 11 mm per degree and during recording of temperature gradient to 46 to 92 mm per degree.

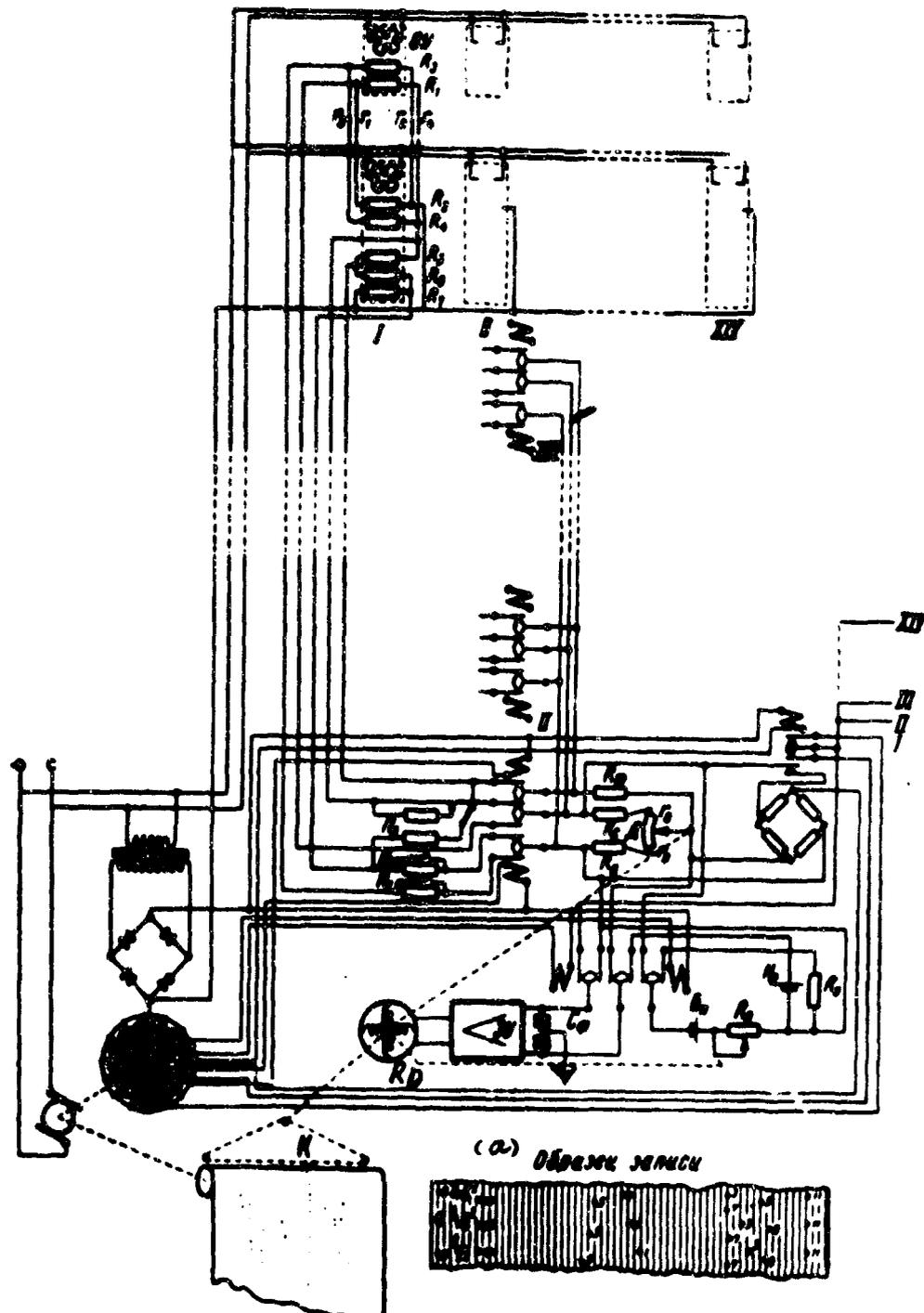


Fig. 11. Fundamental circuit of "thermogradientograph" (measuring and registering block).

KEY: (a) Specimen of recording.

The variation in sensitivity of circuit of "thermogradientograph" is made for the differential bridge by the switch  $\Pi_1$ , and for the complex by switch  $\Pi_2$ . The change of sensitivity can be realized also by varying the ranges of measurement by a corresponding selection of resistances of the circuit  $R_g = \mu(r_g/r_0) = R_0$ , by its shunting, by connecting the resistance  $R_{10}$ , et cetera.

The variation of ranges of measurement is realized by shunting by the switch  $\Pi_3$ .

The connection of measuring circuits to the recorder is realized by a relay switch, operating from a power motor. Here in series there are connected the differential and complex bridges and onto the recorder there are given corresponding voltages of the unbalance.

The variable resistance of the contact mechanism of relay of layered switch of sensing units at the levels  $h_i, h_{i+1}$  ( $i = 1, 2, 3, \dots$ ) is connected not to circuit of bridge (bridge here is closed), but into external circuit with resistance  $R = 2 \cdot 10^3$  ohm. Hence,

$$(dR)_{\text{cont.}} = Ra = 2 \cdot 10^3 \cdot 4,25 \cdot 10^{-3} = 8,5 \text{ ohm} \cdot \text{deg}^{-1}, \quad \alpha = 4,25 \cdot 10^{-3} \text{ deg}^{-1},$$

and the error  $\delta$  to variable resistance during variation of resistance of contact mechanism [46]:  $dR_{\text{Bap}} = 0,03$  to  $0,05$  ohm (and with contamination of points of contact  $0,1$  ohm) will constitute:

$$\delta R_{\text{Bap}} = \frac{dR_{\text{Bap}}}{(dR)_{\text{cont.}}} = \frac{0,03 + 0,05}{8,5} \approx 0,003 + 0,006\%$$

As the basis of principle of measuring and registering the average temperature and the temperature gradients in the layer there is posed the zero method of measurement that is a condition of zero balance of bridge [23]:

$$R_1 R_{1+2} = R_{1+1} R_{1+3}$$

In the circuit of measuring the temperature gradients the copper wire resistances of the differential bridge ( $R_1 - R_2 - R_3 - R_4$ ) comprise the sensitive elements at the levels I( $R_1, R_3$ ) and II( $R_2, R_4$ ), in layer between which is measured the difference between the temperatures  $\Delta\theta = \theta_{i+1} - \theta_i$ ; here a ladder network of manganin resistances  $R_5 - R_6 - R_7$  is the shunting.

Connecting leads of the circuit  $R_1 - R_2 - R_3 - R_4$  introduced respectively to each arm which excludes their influence on operation circuit, and there is no necessity of compensation leads.

In the circuit for measuring the average temperature  $\theta = (\theta_{i+1} + \theta_i)/2$  the differential bridge  $R_1 - R_2 - R_3 - R_4$  is an arm (an equivalent  $R_{\text{экв}}$ ) of the complex bridge  $R_{\text{экв}} - R_5 - R_6 - R_7$ .

In the circuit of the complex bridge at  $R_1 = R_2 = R_3 = R_4$  the equivalent resistance  $R_{\text{экв}}$  will be determined as follows:

$$1/R_{\text{экв}} = \frac{1}{R_1 + R_4} + \frac{1}{R_3 + R_2} = \frac{2}{R_1 + R_2}$$

During

$$\begin{aligned} R_{\text{экв}} &= (R_1 + R_2)/2, \\ R_1 &= R_0(1 + \alpha\theta_1), \\ R_2 &= R_0(1 + \alpha\theta_2) \end{aligned}$$

we have

$$R_{\text{экв}} = R_0 \left( 1 + \alpha \frac{\theta_1 + \theta_2}{2} \right)$$

i.e., by the circuit of complex bridge actually there is measured the half-sums of temperatures at the two levels (in layer).

If temperature of the lower sensing unit is  $\theta_I$  and the upper is  $\theta_{II}$ , then in the circuit of differential bridge the ratio between regulated resistances  $r_8, r_9$  is determined by difference of temperatures at levels I and II [24]:

$$\Delta\theta_{I-II} = \theta_I - \theta_{II} = f(r_8/r_9)$$

Position of the slide D at  $\Delta\theta_{I-II} \neq 0$  depends on  $\theta_I: f(r_8/r_9) = F(\theta_I)$ . This is a weak ratio, but it is considered in constructing the scale of the "gradientograph".

In circuit of complex bridge the ratio  $r_8/r_9$ , and consequently, the position of the slide D is explicitly determined by the half-sum of the temperatures of the sensing unit at the levels:

$$1/2 (\theta_I + \theta_{II}) = \theta_{\text{layer}} = f(r_9/r_8)$$

The signal of the inbalance in measuring diagonal of bridge during measurement of  $\theta$  and  $\Delta\theta$  is amplified by an electronic amplifier EU in series by voltage and by

power and proceeds to the actuating coil of the reversible motor RD, kinematically connected with slide contact (slide) D of rheochord  $r_g/r_0$ . By rotating in either direction depending on the phase (polarity) of initial signal, the reversible motor RD shifts the slide contact of rheochord  $r_g/r_0$  up to compensating of the measuring circuit; here the signal, in being weakened, becomes equal to zero. The slide of rheochord kinematically combined with carriage, which periodically (every 5 to 10 sec) prints on perforated paper tape marks (points) with corresponding number of parameter being measured. These marks fix the position of equilibrium of slide contact of rheochord.

For control in the scheme of the "thermogradientograph" there is introduced a constant bridge for installation (adjustment) of the working current of the power battery  $B_H$  — an independent measuring bridge, replaced by an equivalent resistance  $R_1$ . The resistance of rheochord disconnected from the circuit of recording instrument and connected to the shunting network  $R_g - D(r_g/r_0) - R_0$  of the measuring circuit as a divisor of the resistance (voltage  $D(r_g/r_0)$ ).

Switching of electronic amplifier EU and power supply battery BI with the measuring circuit into the circuit of adjustment of the working current and conversely is realized by a periodic relay group from the power motor by means of a cam transmission. In connecting the circuit of adjustment of the working current there occurs its automatic control by comparing values of the voltage drop in the resistance  $R_1(\epsilon_R)$  and the E.S.U. of the normal element ( $\epsilon_{em}$ ), which are equal to each other, if the working current in the measuring "bridge" is properly established. If  $\epsilon_R \geq \epsilon_{em}$  i.e., the working current is incorrectly established a signal proceeds to the electronic amplifier, the signal compels reversible motor RD to revolve in a direction, corresponding to the polarity of signal. Simultaneously by the kinematic connection RD with the slide of rheostat, which regulates the working current by the slide of rheochord  $D(r_g/r_0)$  and carriage K their corresponding shift up to the establishment of working current at required value is realized. According to the establishment of working current to corresponding switching of the relay

group, the scheme reaches a position, corresponding to the value of the measured magnitude.

In the scheme of "thermogradientograph" a manual setting of the working current is provided for. Its accuracy is determined by errors of the normal element, resistance of the operating circuit and the sensitivity of the zero indicator. In overloading the normal element by a current more than one microampere under room conditions the error in the E.S.U. developed by it according to [54] does not exceed  $\pm 0.01\%$ . In general the accuracy of the measurement by an equilibrium bridge can be reduced to  $\pm 0.01-0.02\%$ .

The adopted paired spacing of actuating arms of bridge in the scheme of the "thermogradientograph" according to levels of measurement (Fig. 12) makes it possible to increase the sensitivity of circuit in comparison with the common spacing of the two actuating bridge arms in the measuring circuits of "gradientographs" by levels.

In a circuit with single spacing the sensing units by levels, for example, at  $R_1 = 110$  ohm,  $R_2 = 115$  ohm,  $R_3 = R_4 = 100$  ohm the "gradient" difference

$\Delta\theta_{I-II} = \theta_I - \theta_{II}$  owing to the difference in temperature at levels of measurement causes an inbalance:  $R_1R_3 \neq R_2R_4$  ( $110 \cdot 100 \neq 115 \cdot 100$ ), is proportional to  $\Delta R = R_2 - R_1 = 5$  ohm, and in the circuit with the spacing in pairs the "gradient" difference between the same levels at  $R_1 = R_3 = 110$  ohm,  $R_2 = R_4 = 115$  ohm causes a greater (intensified) inbalance:  $R_1R_3 \neq R_2R_4$  ( $110 \cdot 110 \neq 115 \cdot 115$ ) which is proportional to  $2\Delta R = 2(R_2 - R_1) = 10$  ohm. But a large inbalance of a circuit with spacing in pairs causes a greater shift of the indicator in comparison with the inbalance of circuit with single spacing with one and the same difference of temperatures between levels I and II ( $\Delta\theta_{\text{paired}} = \Delta\theta_{\text{single}}$ ). Thus, for one and the same difference  $\Delta\theta_{I-II} = \theta_I - \theta_{II}$  the sensitivity of the circuit with spacing in pairs is greater in comparison with the sensitivity of circuit with a single spacing.

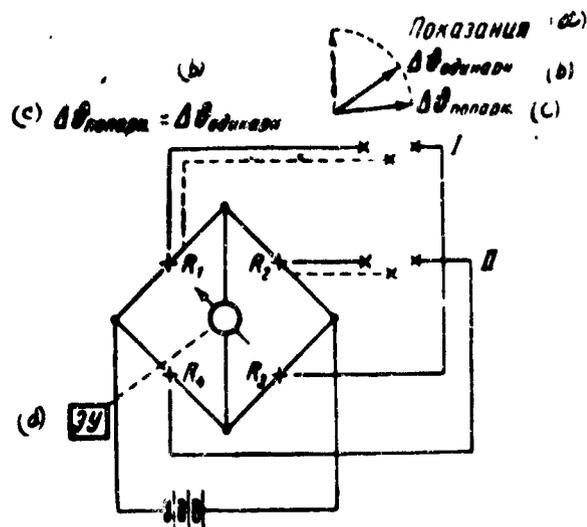


Fig. 12. Circuit of spacing sensors by levels.

I, II — levels

KEY: (a) Readings; (b)  $\Delta\theta$  single; (c)  $\Delta\theta$  paired; (d) Electronic amplifier.

For practical elimination of error of measuring inbalance of operating (arm) resistances of bridge owing to their nominal differences ( $dR \sim d\theta$ ) during a change in temperature these resistances are assumed close with an accuracy 0.05 ohm.

With a strict realization of a bridge balance with a tolerance  $\delta R = 0.05$  ohm there is realized the approximate equilibrium:

$$(R_1 + 0.05) (R_3 + 0.05) \approx R_2 R_4,$$

i.e., the inbalance (at  $R = 220$  ohm) is insignificant.

The adopted tolerance of 0.05 ohm at  $(dR)_{dV} = 1^\circ = 8.5$  ohm corresponds to an error  $\delta R = 0.05 \cdot 1/8.5 = 0.01^\circ$ , that is, it does not exceed the limits of adopted accuracy of measuring the difference ( $\leq \pm 0.03^\circ$ ) and the halfsums ( $\leq \pm 0.1^\circ$ ) of temperature in the layer.

The bridge resistances are selected close within the limits of the adopted tolerance  $\delta R = 0.05$  ohm for the entire range of temperatures being measured, for which there are selected resistances with coinciding characteristics  $R_1 = R_1(\theta_1)$  in the range of temperatures from  $-40$  to  $+40^\circ\text{C}$  and with the difference of their resistances at extreme points ( $-40$  and  $+40^\circ$ ) to 1 ohm. For this purpose the bridge (measuring) resistances are calibrated at many points. The corresponding

graphs are obtained and the sensing units with approximate (coinciding) characteristics are selected.

According to the adopted scheme of the "thermogradientograph" at intermediate levels there located paired resistances thermometers which makes it possible to conduct control of measurements of one of them by the other.

According to measurements, for example, in layer I—II there are determined the mean value of temperature in this layer  $\bar{\vartheta}_{I-II} = (\vartheta_I^* + \vartheta_{II})/2$  and difference of temperature in this layer  $\Delta\vartheta_{I-II} = \vartheta_I^* - \vartheta_{II}$  and hence the values  $\vartheta_I^*$  and  $\vartheta_{II}$ .

From the measurements in the layer II—III there are determined  $\bar{\vartheta}_{II-III} = (\vartheta_{II}^* + \vartheta_{III})/2$  and  $\Delta\vartheta_{II-III} = \vartheta_{II}^* - \vartheta_{III}$  and correspondingly  $\vartheta_{II}^*$ ,  $\vartheta_{III}$ ; here  $\vartheta_i^*$  and  $\vartheta_i$  (with asterisk and without asterisk) are the temperatures on one level, determined from adjacent independent circuits.

The control is realized by comparing the values  $\vartheta_{II}^*$  and  $\vartheta_{II}$  et cetera, that is the temperature at a level can be obtained from the readings two independent bridges which makes it possible to control accuracy and to determine discrepancy of measurements  $\Delta = f(\tau)$  ( $\tau$  —time), which develops with time owing to the aging of resistance thermometers and must not exceed the limits of accuracy of measurement.

The determination of discrepancy is made as follows:

$$\left. \begin{array}{l} \text{In the layer} \\ \text{I—II: } (\vartheta_I^* + \vartheta_{II})/2 = A, \\ \vartheta_I^* - \vartheta_{II} = B \end{array} \right\} \quad \left. \begin{array}{l} \text{in the layer} \\ \text{II—III: } (\vartheta_{II}^* + \vartheta_{III})/2 = C \\ \vartheta_{II}^* - \vartheta_{III} = D \end{array} \right\}$$

at the level II:  $\vartheta_{II} = A - B/2$ ;  $\vartheta_{II}^* = C + D/2$ , where ABCD —are the measured values.

Hence discrepancy is determined from the expression

$$\Delta = \vartheta_{II}^* - \vartheta_{II} = (A - C) - (B + D)/2.$$

The variation in the discrepancy of readings of adjacent sensing units of independent schemes occurs for various reasons, the chief of which are the following: aging of piece parts of instruments (in particular the thermistors), nonsystematic errors of apparatus, which are reflected in various ways by readings

of upper and lower measuring bridges, the shifting in time (nonsynchronization) of recording traces of measurements, and also errors, associated with microoscillations of the air temperature or in processing the results of measurements et cetera.

As the piece parts become older the magnitude of the discrepancy  $\Delta$  should approach a constant value. Its oscillations must persist in which the deviations of  $\Delta$  from the average should be smaller the greater is the interval of the averaging of the results of the measurements.

A discrepancy determined from the discussion above involves errors of measurement of the average temperature of layer I—II and adjacent layer II—III

( $\delta\theta_{I-II} = 0.2^\circ$ ;  $\delta\theta_{II-III} = 0.2^\circ$ ) and of errors of measurement of differences of temperature in these layers ( $\delta\Delta\theta_{I-II} = 0.05^\circ$ ;  $\delta\Delta\theta_{II-III} = 0.05^\circ$ ), i.e.,  $\Delta\delta\theta_{I-II} + \Delta\delta\theta_{II-III} + \delta\Delta\theta_{I-II} + \delta\Delta\theta_{II-III} = 0.5^\circ$ .

An analysis of variation of the discrepancy, made on the basis of measurements on the high tower and by other measurements, shows the dependence of its variation on conditions of power supply of the circuits of the wind speed (more precisely — pulsations of wind) et. al. A good variation of the discrepancy is observed with a fixed power supply for the schemes and under stable conditions in atmosphere, in which also there should be made a checking of the schemes for discrepancies.

For a resistance thermometer in a bridge circuit from a common solution of the temperature function:  $R_t = R_0 e^{\alpha\theta}$  and equilibrium conditions.  $R_0 R_{t+1} = R_t R_{t+2}$  there it is calculated  $\theta = \frac{1}{\alpha} \ln \frac{R_t R_{t+2}}{R_0 R_{t+1}}$  —the temperature of sensing unit or the equivalent resistance which is used in calibrating and checking the measuring. Calibration and checking of the "thermogradientograph" can be realized both by the indicated methods of discrepancy and equivalent resistances, and also by the method of reference points by the thermostatic control of the resistance thermometers.

On the high tower the utilized scheme of the "thermogradientograph" has been designed for measuring the average temperature and difference between temperatures

in the layer, in a range from  $-45$  to  $+45^{\circ}\text{C}$ .

From experience in using the "thermogradientograph" V. D. Andreyev, V. S. Storozhko, B. P. Zotov and the author introduced in its design and operating scheme certain changes.

As, the spaced sensing units in the former circuit with the actuating arms of adjacent layers are combined in a common sheet with common aspiration; here the main arms of complex bridge ( $R_5, R_6, R_7$ ) extending out from the sensing unit to the individual unit. The design of the sensing unit was realized so that its sensitive element can without disassembling of sensor unit be checked by the reference points in the thermostat.

The relay connection of the sensing units to the recorders is reduced to a unit on the panel with the common power supply for it.

For reliability of operation of the relay switching mechanisms there are installed relays with platinum contacts and there is introduced luminous indication of the connections of the circuits.

The aspiration of sensing units is shifted to a low-voltage supply (24 v) which is essential from the point of view safety of operations on metallic structures

There is introduced a common shunting resistance for all layers for ranges in measuring temperature differences of  $\pm 1.5$  and  $\pm 3.0^{\circ}$ .

For the thermocompensation the resistances are made of copper and are extended to the sensing units under identical conditions with them. This creates a partial thermocompensation in corresponding branches of the measuring bridge.

Zero of temperature scales with adjusted resistances is reduced to a single ordinate.

The outlet resistances of the measuring schemes of the temperature and temperature difference are equalized and matched with input impedance of corresponding amplifiers of the recording instrument.

The monitoring of the operation of the scheme of thermogradientograph and its

regulation is reduced to a common panel. Switching of circuits is simplified by reducing the switching to one common switch.

Merits of the considered scheme of thermogradientograph include: an accuracy of  $0.1$  to  $0.3^\circ$ —in measuring the temperature,  $0.03$  to  $0.05^\circ$ —in measuring the difference between temperatures; the possibility of a direct measurement of difference of temperatures; absence of tensometric effect in the sensing units, the closure of measuring bridges, by which there is excluded variable resistances; compensation of connecting leads of the differential bridge; the paired spacing of the sensing units by levels which increases sensitivity of circuit in comparison with sensitivity of circuits with single spacing of actuating arms —of sensitive elements— of the measuring bridge; developed methodology of verifying by equivalents, possibility of checking by reference points and monitoring for discrepancy of readings of sensing units at one level by independent circuits.

The use in the scheme of a thermogradientograph of resistance thermometers with a high resistance ( $220 \text{ ohm}$ ) makes it possible to maintain condition of balance with deviations of the resistances from a nominal value with a tolerance up to  $0.05$  or somewhat higher ohms which simplifies the requirements for tolerances in sampling resistances of adjacent bridge arms.

#### The Measurement and Registration of Humidity

The apparatus for measuring humidity in 300-meter layer of atmosphere on a high tower must satisfy the following requirements: prolonged reliable automatic operation, stable calibration, stability of time constant, high sensitivity to small moisture contents, with which there are definite difficulties of distinguishing vapors in the air in pure form, the measurement of humidity in a wide range of temperatures from  $+40^\circ$  to  $-45^\circ\text{C}$  and the discrimination of the phase state of water vapors in the atmosphere.

To these conditions there do not wholly correspond such methods of measurement of humidity in atmosphere, as psychrometric, thermoelectrolytic, sorptional,

curvature; the dew-point method, method of thermal conductivity and specific dielectric capacitance of moistened air depending upon degree of its humidity et al.

Defects of the indicated methods of measuring the humidity of air [55] limit the possibility of their application, therefore it is necessary to develop and to adopt new methods of measuring humidity on high-towers, where the servicing of the apparatus is difficult specially the sensing units on projections out from the tower.

A prospective method of measuring humidity of air is radiation (spectrum), based on dependence of degree of absorption of infrared radiation of a specific wave length on the humidity of investigated gas (infrared hygrometry).

The essence of spectral method of measurement of humidity, worked out in reference to conditions of measuring the humidity in the complex of a high tower, consists in the following. Components of atmospheric air, selectively absorbing the solar radiation, are water vapors and carbon dioxide. The exponential law of Lambert—Bouguer [41] is

$$I_{\lambda} = I_0 \lambda e^{-\alpha_{\lambda} d},$$

where  $\alpha$  is the absorption coefficient,  $d$  —the thickness (mass  $m$  of the absorbing medium), in the infrared region with an unresolved structure is not fulfilled, because  $\alpha = \alpha(\lambda, m) \neq \text{const}$ . The dependence  $D \approx f(m)$  ( $D = \ln I_0/I$  is the optical density), corresponding to exponential law for absorption bands of water vapors, according to calibration [43] is nonlinear. In the region of water vapor values in the atmosphere with the nonresolution of structure of spectrum, i.e., with a spectrometer band width ( $b$ ), significantly exceeding the spectrum resolution of the band  $(\Delta\lambda): b \gg \Delta\lambda$ , the exponential law is not fulfilled.

The use of the exponential law in this case stipulates the necessity of introducing an effective absorption coefficient ( $K_m^{*}$ ).

Optical density  $D$  is function of  $K_m^{*} \times m$ .

$$D = \ln(I_0/I) = f(K_m^{*}; m).$$

The absorption of radiation by water vapors in the infrared region with an unresolved structure of the band on the assumption of dispersion form of the lines, quantitatively is satisfactory governed by empirical law of the square root [34, 65].

$$A = 1 - I_0/I = k\sqrt{m},$$

where  $A$  is a function of the absorption,  $m$  is the mass of water vapors in investigated volume of air,  $k$  is the constant being determined during calibration of the instrument, depending on width of spectrum interval resolved by the instruments and of conditions of the temperature experiment and total atmospheric pressure,

$$k = C \sqrt{\rho/\rho_0} \sqrt[4]{\theta/\theta_0}.$$

Here  $\rho_0$ ,  $\rho$  and  $\theta_0$ ,  $\theta$  are the pressure and air temperature under normal conditions and conditions during measurements;  $C$  is a factor, characterizing structure of unresolved spectrum.

The relation  $k = f(p, \theta)$  is determined by dependence of absorption on the line width. The function  $A = f(m^{1/2})$  is nearly linear [43].

According to [78],  $A = f(\delta^{1/4})$  and the corresponding correction will attain 2 to 5%.

Absorption bands of water vapor, liquid water and ice are somewhat displaced over the spectrum [79, 90]; below there are indicated the position of maxima of the absorption bands ( $\mu$ ):

Vapor . . . . .	1.38	1.87	2.70
Liquid water . . . . .	1.43	1.94	2.92
Ice . . . . .	1.26—1.29	—	3.07

Such a displacement of the absorption bands make it possible in principle to measure by the spectral method of water in different aggregate states, individually.

The phase state can be distinguished also by the intensity of absorption bands of radiation [8]. By the use of more intense absorption bands there will be attained a high accuracy and sensitivity of spectral method of measurements of small concentrations of water in the atmosphere.

The direct use of depleting the radiation in different absorption bands for determining the water content in corresponding aggregate states is difficult,

inasmuch as in finely disperse systems (atmospheric haze, fog) effect of diffusion can exceed the effect of absorption. Here it must be noted that absorbing properties of continuous and dispersed media are different.

The intensity of the diffuse radiation and, consequently, depletion associated with diffusion, depend on wave length of the incident and dimensions of dispersing particles ( $d$ ).

With  $d \ll \lambda$  the diffusion can be ignored, and the depletion of radiation is caused mainly by absorption. With an increase in  $d$  the role of diffusion increased

Most complex is the system  $d \approx \lambda$ . In this case there is observed a nonmonotonic dependence of the scattering coefficient  $K$  on  $\lambda$  with obvious minima (selective transparency) and maxima.

The qualitative explanation of selective transparency can be associated with an anomalous variation of index of refraction  $n$  in the region of absorption bands, inasmuch as  $K = K(n)$ .

A direct determination by the spectral method of the contents of water vapors in the atmosphere is fulfilled, for example, [29, 44] by discriminating in the infrared sector lines 1.24; 1.40; 1.50; 1.88; 2.2  $\mu$ ; here the lines 1.40, 1.88  $\mu$  belong to the absorption bands of water vapor. The use of the two bands widens the range of measured concentrations of water. The use of lines 1.24; 1.50; 2.2  $\mu$ , intermediate between absorption lines 1.40; 1.88  $\mu$ , makes it possible to determine by interpolation the sensitivity of the latter.

As dispersive (resolving) system there is used a monochromator with a diffraction grating, which with a special cam mechanism engages the corresponding five positions, in series by leading the indicated lines to the receiver.

The use of diffraction gratings as a dispersive (resolving) system makes it possible to attain in comparison with prisms a greater candle-power of the monochromators in the radiation flux with the maintenance of a high resolving power.

As receiver of radiation in the schemes of the spectral hygograph there is

used a cooled photoresistance of PbS, sensitive to short-wave region of the infrared spectrum at the long-wave boundary  $0.7\text{--}3.0\ \mu$  .

In the scheme of the spectral hygograph with a diffraction dispersion radiations from the infrared source of the operating range ( $0.7\text{--}3.0\ \mu$ ) are decomposed by a diffraction grating in the reflected light into a spectrum. With oscillations of the grid the spectrum is shifted, so that radiation from its sectors gradually proceeds to the receiver. Current being excited in the receiver are amplified and are conveyed to the recorder.

In the scheme with filters of radiations from an infrared source there will emanate radiations of the hydrographs acting spectral sectors, which directly proceed to the receiver, et cetera.

The scheme of a spectral hygograph with filters is simpler both in optical principle and technically. The kinematics of the shifting of the resolving (dispersive) system here also is simpler, than in schemes of a spectral hygograph with a diffraction dispersion.

At the present time there is being realized a development of an optimum scheme for the complex of the high tower; here in the scheme being developed as resolving system the use of a system of light filters with an adjusted stability, with fairly narrow pass bands and the eliminated thermal "creep" of filters over the range of long waves which are passed by them, is proposed.

The scheme of spectral hygograph is being developed for measuring the humidity in a range of temperatures from  $+40$  to  $-45^\circ\text{C}$ ; errors of measurement with a partial pressure of water vapors in atmosphere within the limits of 1 to 20 mm will constitute 3--5%, and up to 1 mm -- a somewhat higher percent.

The principal advantage of developed radiation (spectral) method of measuring humidity, based on use of selective dependence of degree of absorption of infrared radiation on humidity of air is the fact that this method is direct, highly sensitive (that is, it has little inertia) and at the same time the sensitivity

with decreasing water vapor and with decreasing spectrum width of the radiation pencil increases; the method we shall apply for measuring the humidity during low negative temperatures, possesses a stable calibration, a stable time constant, these make it possible to distinguish the phase states of the water vapors in atmosphere, to average the measurements on a variable base et al.

### On Radiation Measurements

The measurement and recording of radiation characteristics are introduced in a system of complex automatic measurements in the lower layer of atmosphere for studying the association between radiation and meteorological parameters. Radiation, transfer and absorption of radiant energy in the lower layer of atmosphere especially owing to the long-wave radiation stipulates to a certain extent the thermal conditions in this layer, its temperature gradients et al. which, in turn, exerts an influence on meteorological processes in it. At the present time in complex of radiation measurements on the high tower there has been developed an automatic remote control registration of the direct, total (global) diffuse and reflected radiations and of the radiation balance. The corresponding schemes were developed by S. T. Mashkov with the participation of Z. I. Volkovitska, N. G. Stefanov, et al.

As radiation receivers there have been adopted the corresponding standard instruments -- actinometers, pyranometers, albedometers, and balancemeters.

In order to avoid discrepancies caused by oscillations of overhead wires in the Earth's magnetic field (up to 50 microvolts) there has been introduced well shielded wiring of the radiation-measuring lines from sensing units to the recording instruments.

The recording of the radiation balance of total, direct diffuse and reflected radiations is realized by a six-point recording instrument eKV with a discreet recording according to potentiometric scheme with a scale for registering the balance up to 5 millivolts for registering the direct, total diffuse and reflected

radiations up to 16 millivolts; here error of recording trace amounts to  $\pm 0.5\%$  of the limit of the measurement.

The rates of unwinding of recording chart amounts to 60 mm per hour that is a rate satisfaction for a practical discrimination of the recording marks.

#### Certain Results of Experimental Gradient Measurements

Certain results of experimental gradient measurements made on the high tower are illustrated in Fig. 13.

In Fig. 13 there are presented examples of measurements of vertical profiles for different periods (a) and temporal variations of the wind speed for different levels (b) averaged for each 10 minute-period.

In Fig. 13 there are given examples of variations in wind direction in the vertical (c) and variation in time (d) smoothed within error of  $5-10^\circ$  and averaged for 10 minutes. These measurements were made by one-dimensional "rhumbograph".

In the figure there are evident occurrences of the wind turning to the left.

In Fig. 13 are presented examples of measurements of vertical profiles (e) and of variations with time (f) of temperature for different levels in the 300-meter layer, smoothed within error of  $0.5^\circ\text{C}$  and with averaging for a 10-minute interval of time.

Profiles of temperature for the routine observation hours (0100, 0700, 1300, 1900) make it possible to trace disappearance of surface inversion from morning to noon and its reformation in the afternoon. Temperatures and wind speeds have been calculated for the profiles at the 0700 hr observation in the 97-217 m and 25-97 m layers. The Ri numbers ( $Ri_{97-217\text{m}} = -0.08$  and  $Ri_{25-97\text{m}} = 0.23$ ) indicate the stability in the lower 25-97 m layer and a weakly expressed instability in the 97-217 m layer.

In temporal variation of the temperature there is observed decrease in the range and displacement of maximum of temperature with height.

## 2. Structural (Pulsational) Measurements

For routine operations and for investigating the lower layer of atmosphere of great interest is the measurement of turbulence characteristics by means of measurements on towers: pulsations of wind speed and direction of temperature and humidity of spectra and energy of any one components of the wind speed and also of direct measurement of heat fluxes and momentum.

At present the measurement and recording of horizontal component of the pulsation of wind speed is made on a high tower by a st. in-gauge "pulsationograph", fundamental circuit of which is presented in Fig. 14. The circuit includes a strain-gauge sensing unit, a power-source unit of direct current with a voltage of 30 v with control of power supply in current and on voltage of recorder — a single-channel potentiometer EPP-0.9 with time of run of carriage 1 sec. As sensing unit in the scheme of strain-gauge "pulsationograph" there is used braked anemometer with a strain-gauge converter [53], which is a four-armed equilibrium bridge, composed of strain-gauge resistances — strain-gauges  $r_1, r_2, r_3, r_4$ , made of 0.03 mm constantan wire. Tensometers are glued in pairs on two mutually perpendicular lines onto the surface of an elastic tube of aluminum alloy with a diameter of 8 mm. The tube is the shaft of cup receiver with 21 hemispheres. The elastic deformation of the tube's torsion caused by the wind pressure on pickup part which are, proportional to square of the wind speed subject the strain-gauges in pairs to elongation and compression, owing to which there occurs change of resistance ( $\Delta r_x$ ) in the arm of the Wheatstone bridge being formed by them, and consequently, of its imbalance which is recorded by a sensitive recorder. The relative change of the "tensometer resistance" owing to its deformation is expressed as:

$$\frac{\Delta r_x}{r} = f\left(\frac{\Delta l}{l}\right) = f(\sigma).$$

where  $\frac{\Delta l}{l}$  is the relative deformation,  $\sigma$  is the voltage in wire.

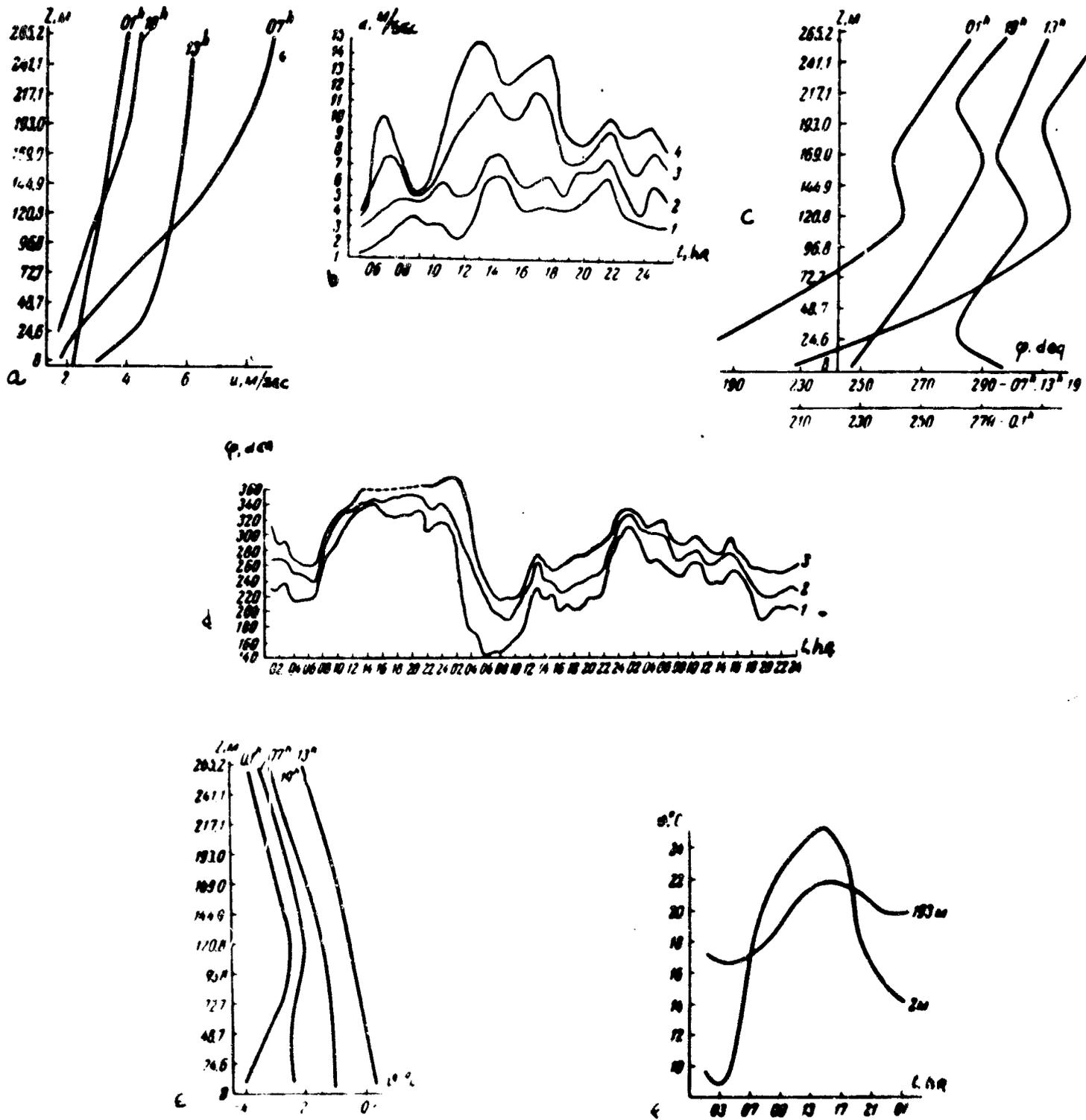


Fig. 13. Vertical profiles (a, g, e) and temporal variations (b, d, f) by levels in lower 300-meter layer of atmosphere according to experimental measurements on a lofty tower. a -- wind speed 16 March 1961; b -- wind speed 11 -- 12 March 1961; 1 -- height above earth 8; 2 -- 127; 3 -- 193; 4 -- 265.2m; c -- wind direction on 16 March 1961; d -- wind direction 10 -- 12 March 1961; 1 -- height above earth 24.6, 2 -- 72.7, 3 -- 265.2 m; e -- temperature 16 March 1961; f -- temperature.

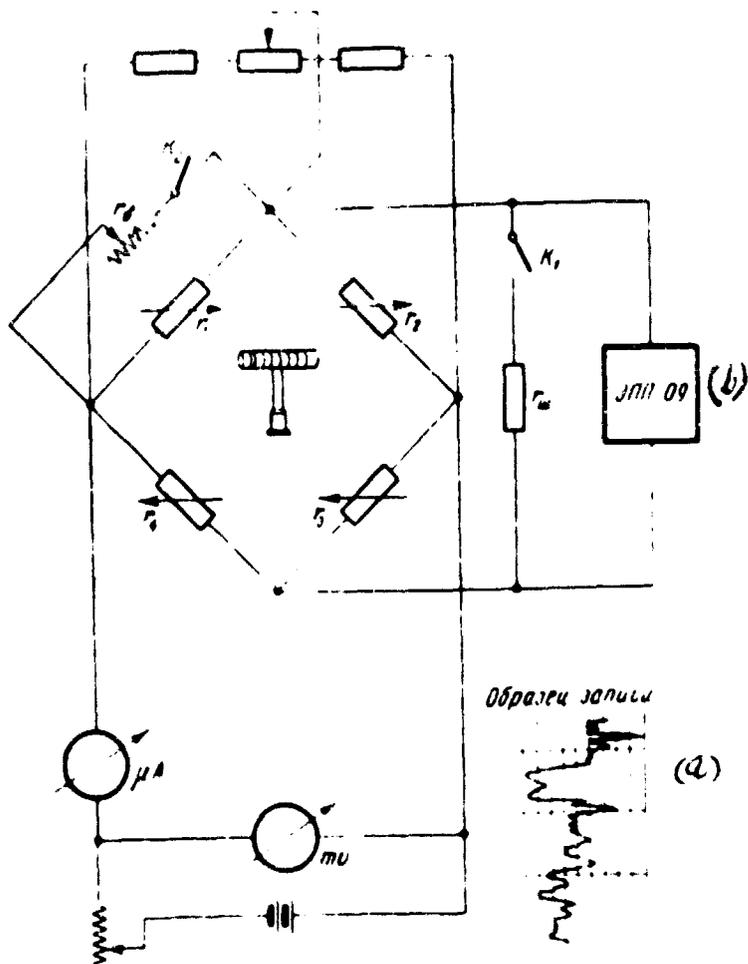


Fig. 14. Fundamental circuit of strain-gauge "pulsationograph".  
 KEY: (a) Specimen of recording trace; (b) EPP-09.

The dependence is linear [54] and can be presented in the form of  $\frac{\Delta r_x}{r} = K \frac{\Delta l}{l}$ ,  
 here  $K = 1.9 - 2.1$  (for constantan) — sensitivity of the "tensoresistance". Within  
 the limits of the elastic deformations ( $\frac{\Delta l}{l} = 2.5 \cdot 10^{-3}$ ) [54]:

$$\frac{\Delta r_x}{r} \approx 5 \cdot 10^{-3} \approx 0.5 \epsilon_e.$$

by which there is determined the deformation error of sensitive element of strain  
 gauge.

The sensitivity of the strain gauges  $\gamma$  is determined from the ratio

$$\gamma = \frac{\Delta r_x / r}{\Delta l / l}.$$

Owing to baking of wire onto a "veniflex" base (lacquer VL-6) the sensitivity  
 of strain-gauge maintains a constant value both during elongation and also during

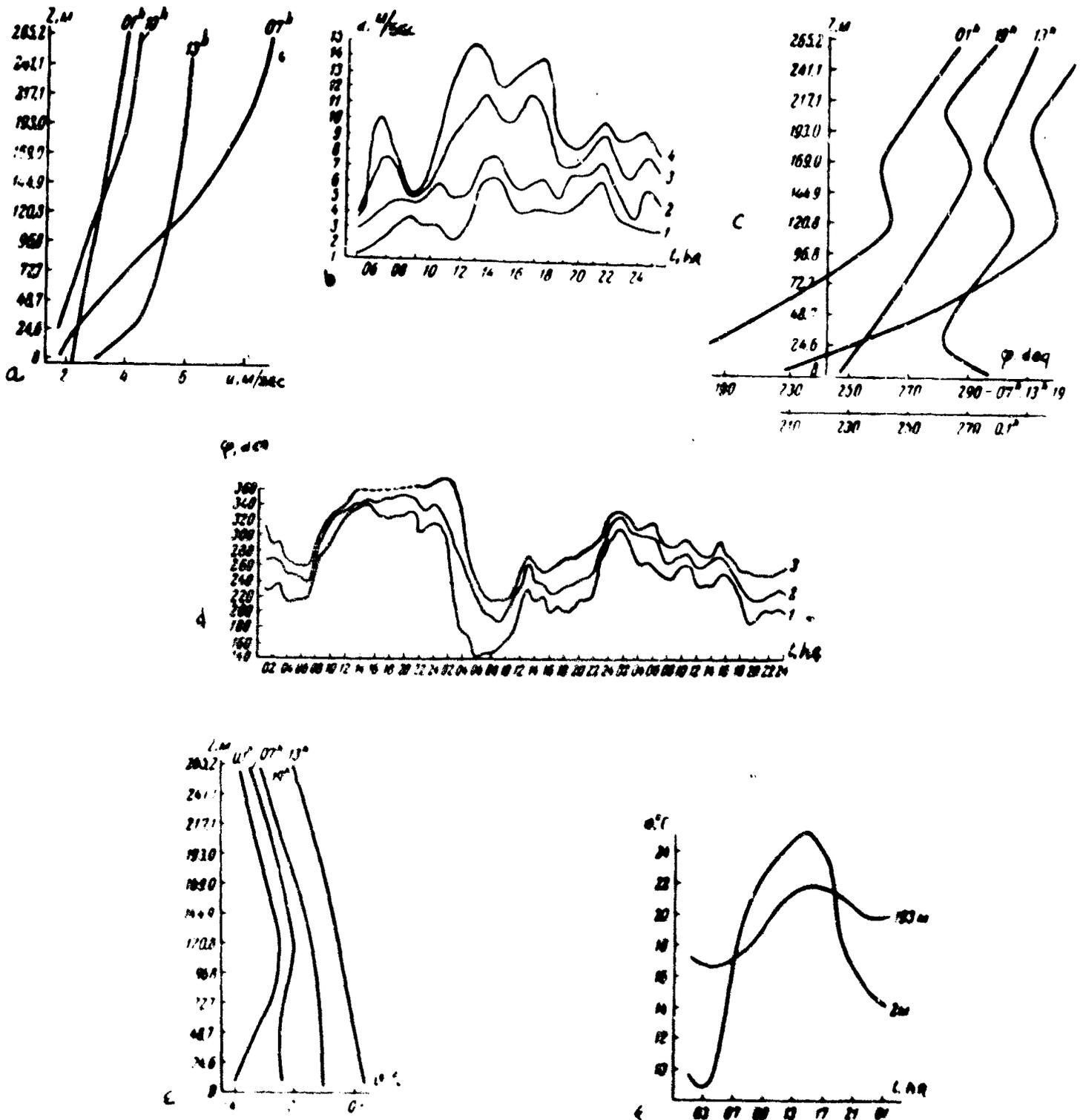


Fig. 13. Vertical profiles (a, g, e) and temporal variations (b, d, f) by levels in lower 300-meter layer of atmosphere according to experimental measurements on a lofty tower. a — wind speed 16 March 1961; b — wind speed 11 — 12 March 1961; 1 — height above earth 8; 2 — 127; 3 — 193; 4 — 265.2m; c — wind direction on 16 March 1961; d — wind direction 10 — 12 March 1961; 1 — height above earth 24.6, 2 — 72.7, 3 — 265.2 m; e — temperature 16 March 1961; f — temperature.

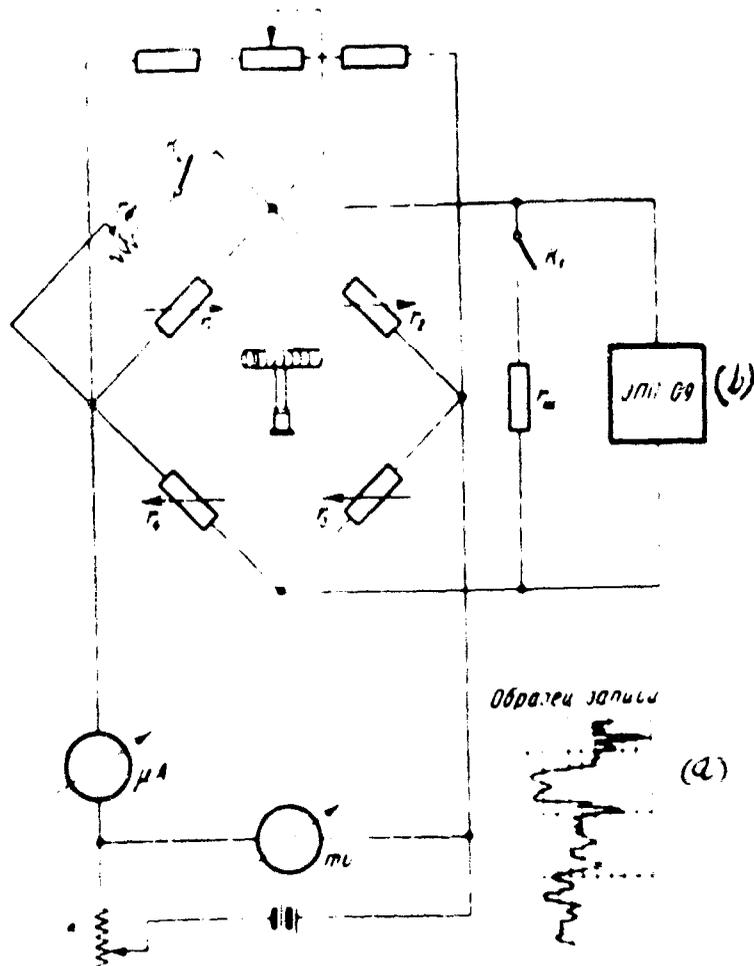


Fig. 14. Fundamental circuit of strain-gauge "pulsationograph".  
KEY: (a) Specimen of recording trace; (b) EPP-09.

The dependence is linear [54] and can be presented in the form of  $\frac{\Delta r_s}{r} = K \frac{\Delta l}{l}$ ,  
here  $K = 1.9 - 2.1$  (for constantan) — sensitivity of the "tensoresistance". Within  
the limits of the elastic deformations ( $\frac{\Delta l}{l} = 2.5 \cdot 10^{-3}$ ) [54]:

$$\frac{\Delta r_s}{r} \approx 5 \cdot 10^{-3} \approx 0.5\%$$

by which there is determined the deformation error of sensitive element of strain  
gauge.

The sensitivity of the strain gauges  $\gamma$  is determined from the ratio

$$\gamma = \frac{\Delta r_s / r}{\Delta l / l}$$

Owing to baking of wire onto a "veniflex" base (lacquer VL-6) the sensitivity  
of strain-gauge maintains a constant value both during elongation and also during

compression; for this reason a tensometer can normally operate even during deformations, exceeding the elastic limit of a wire, as it returns during unloading to its initial resistance. The baking of the wire in a layer of thermal insulation material protects tensometer from influence of heat fluxes, since electric resistance of metallic wire is much more sensitive to changes of temperature, than to changes in deformation.

For tensometers the function  $r = f(\Delta l)$  ( $\Delta l$  — deformation of tensometer) is unstable. In view of this the strain gauge sensing elements will be subjected periodically to a control check.

The tensometric bridge  $r_1 - r_2 - r_3 - r_4$  is thermocompensated, since with a change of temperature all tensometers glued onto tube ( $r_1 = r_2 = r_3 = r_4 = 400 + 0.5 \text{ ohm}$ ), being under identical temperature conditions, obtain identical increments of resistances ( $\Delta r_0$ ) i.e., there is fulfilled the condition:

$$r_1 + \Delta r_0 = r_2 + \Delta r_0 = r_3 + \Delta r_0 = r_4 + \Delta r_0$$

and the balance of bridge is not disturbed. Here it is essential that  $\Delta r_0 \ll r = 400 \text{ ohm}$ .

The calibration of sensing element of strain gauge paired with the recording instrument (EPP-09) is realized by the electromechanical method. By corresponding loads, applied to cup receiver (the arm moves about 100 mm) there are created strains with a torque of  $M$  in  $\text{kg}\cdot\text{cm}$ . Deviations of the recording instruments carriage caused by these torques are marked off by corresponding values of wind  $U$  speed from the calibration curve of the sensing unit:

$$U = f(M).$$

The sensing units are calibrated preliminarily aged by natural aeration on tower for a period of more than a month. The zero-setting of the sensor unit is realized by a high-resistance (order of hundred of kilohms) balance shunt  $r_{sh}$ . The sensitivity is altered by a shunt  $r_j$  (up to tens of kilohms).

The dependence of output voltage of recording instrument on the wind speed

(U m/sec) and corresponding deviation of carriage of recording instrument along scale in a pulsational anemograph is nonlinear. Error of measurements of strain-gauges sensing elements assumed as the root-mean-square deviation of their readings from the curve  $H = f(U)$ , constructed on the basis of the mean values of 10 sensor units, amount to 0.1 — 0.3 m/sec. This does not go beyond the limits of the class of accuracy of recording instrument (0.5%) in the 0 to 40 m/sec range of speeds.

The sensitivity of sensing unit with the wind speed  $U = 10$  m/sec amounts to  $0.15 \frac{\text{mV}}{\text{m/sec}}$ ; with the wind speed  $U = 30$  m/sec —  $0.3 \frac{\text{mV}}{\text{m/sec}}$ . Such a low sensitivity of the sensor unit limits possibility of full-value registration of the pulsations in the standard scale of recording instrument EPP-09 at a 10 millivolt lower limit of measurements of wind speed of an order of 10 m/sec.

A broadening of the range of the pulsations being recorded in range of lower speeds (down to 5 m/sec) in the scheme of a strain-gauge "pulsationograph" is realised by extending the scale of potentiometer EPP-09 to 1.5 millivolt by means of shunting its operating rheochord.

The accuracy of reading of wind speed pulsations on the scale of recorder depends on average speed and amounts to 0.5 m/sec for  $U = 5$  m/sec and 0.1 m/sec for  $U = 40$  m/sec with intermediate values between these speeds.

The adopted rate of unwinding of recording graph of an order of 10 m/sec assures the solution of the maximum frequency (1—2 cycles per second) allowable on the recording paper or tape.

The scheme of a strain-gauge "pulsationograph" possesses the essential defects which distort the spectrum of speed pulsations. These defects include the resonance properties of the sensing unit: it has a natural frequency  $f_{\text{natural}} = 25$  cycles per second with a high Q i.e.,  $Q = 60$ . This reduces to the fact that the natural frequency of the sensing unit makes difficult the possibility of a recording-trace of the pulsations in the interval of frequencies, near the resonance. The sensing unit has zero drift and operates paired with an average wind speed anemometer since

its sensitivity depends on the wind speed. The longitudinal component of the pulsation of wind speed is measured while the transverse and vertical components of the pulsation of wind speed are not discriminated. The very low sensitivity of the sensing unit ( $0.05 - 0.3 \frac{\text{mV}}{\text{m/sec}}$ ) with a prevalence of pulsations of an order of 1 to 2 m/sec makes difficult the automation of processing, since the signals are difficult to amplify.

For measuring pulsations of the wind speed there are used hot-wire anemometers. The principle of their operation is based on the relationship between heat transfer of heated body (for example platinum or tungsten filament) and the speed of air [54, 35].

These schemes are used in experimental investigations, but their introduction into the system of structural measurements on a lofty tower is limited by certain of their defects. For example, the change in temperature of the air flowing onto the filament shifts its calibration curve, because the heat transfer of the filament is proportional to the difference between the temperatures of filament and the onflowing air. Application of high temperatures in heating decreases this effect ( $\theta_{pr} - \theta = \theta_{pr}$  at  $\theta_{pr} \gg \theta$ ), but results in a rapid deterioration of the wire filament. Strong incandescence of filament, besides, distorts field of speed and increases the inertia of the filament. Calibration curves of hot-wire anemometers have a very clearly expressed nonlinearity [25]. The linearization of a calibration is associated with a great complication of the scheme.

Stability of calibrations of hot-wire anemometer schemes is inadequate, since under action of dynamic flow the filament is elongated over its entire length and specially at points in contact with holders; this causes a tensometric effect, and also alters its cross-section.

Instability and nonlinearity of hot-wire anemometric sensor units significantly complicates the automation of statistical processing of measurements of wind speed pulsations.

From the enumerated defects certain acoustical instruments are free, a "biannovans" micro-anemometer et al. [4, 18, 19, 58, 63]. The first of these was used in experimental measurements on a lofty tower.

Measurement and registration of temperature pulsations in experimental measurements on a lofty tower were made pulsational thermometer (micro-thermometer) [59].

At the present time there are also being developed acoustical micro-thermometers [42, 57]. Fundamental scheme [42] is analogous to the scheme of an acoustical anemometer [4], but, in distinction from the latter, where used the method of determining the wind speed by phase difference, in the scheme of an acoustical micro-thermometer there is used the method of determining the temperature by sum of the phases.

Experimental measurements of the root-mean-square values of pulsations of wind speed components, heat fluxes, turbulent friction et cetera were realized in the system of structural measurements on a high lofty altitude tower by a "correlograph" [5, 6], in whose scheme the signals are multiplied up to a frequency of 700 cycles per second.

The linearity of a "correlograph's" scale is maintained in the range of frequencies of 0.05—500 cycles per second. The accuracy of the measurement amounts to an order of 3% of the maximum measurable magnitude and is stipulated by the accuracy of reading along the scale of measuring instrument and interferences in the scheme. Determination of spectra was made by means of low-frequency analyzer of the spectra [6].

The system of structural measurements presently being worked out in experimental models for the lower 300-meter layer of atmosphere, that is, the systems in the complex of automatic meteorological measurements on a lofty tower, includes: the measurement of pulsations of wind speed; pulsations of the temperature; direct measurements of root-mean-square values of the pulsations, heat fluxes, turbulent friction et al.: the measurement of frequency and range characteristics of pulsations of meteorological parameters.

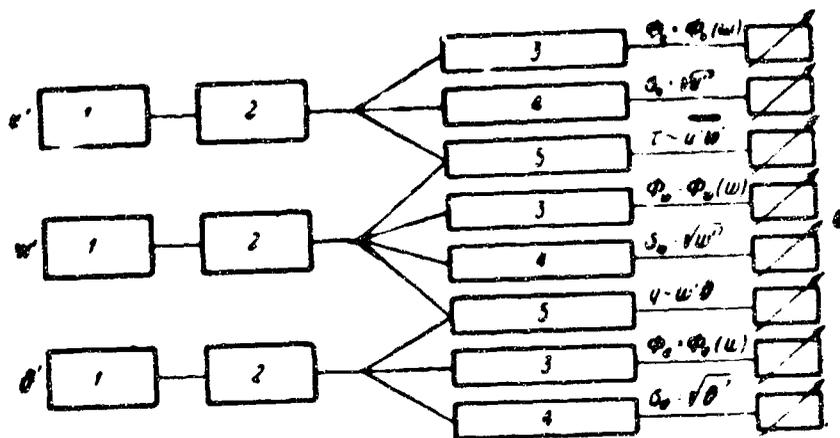


Fig. 15. Block diagram of complex "turbuligraph".  
 1 — sensing unit; 2 — measuring scheme; 3 — frequency analyzer; 4 — "dispersograph"; 5 — correlograph; 6 — recording instruments.

The entire system of structural (pulsational) measurements, in our opinion, should be covered by the scheme of a complex "turbuligraph" (Fig. 15) for measuring the mixing characteristics (turbulence).

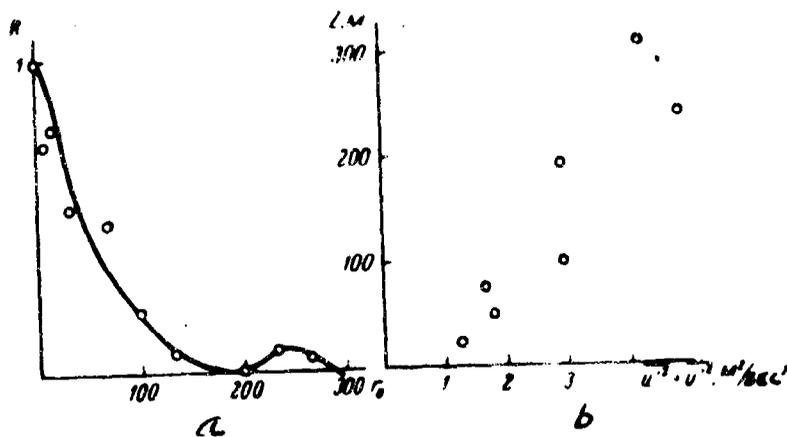


Fig. 16. Longitudinal correlation function (a) and the variation of turbulent energy with height (b), determined by measurements of horizontal pulsations of wind speed on lofty tower.

Figs. 16a, and 16b illustrate the measurements made on a tower by means of tensometric pulsatiograph of turbulence characteristics of the field of speeds [22].

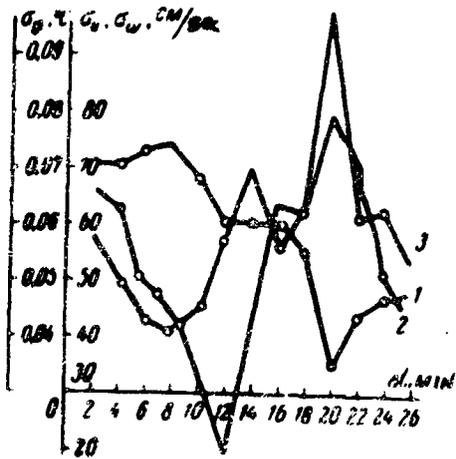


Fig. 17. Variation in time of dispersion of pulsations of horizontal and vertical components of wind speed and of temperature.

1 -  $\sigma_U = \sqrt{U'^2}$ ; 21/VI 1960 r.; 2 -  $\sigma_W = \sqrt{W'^2}$ ,  
22/VI 1960 r.; 3 -  $\sigma_\theta = \sqrt{\theta'^2}$ ; 4/VII 1960 r.

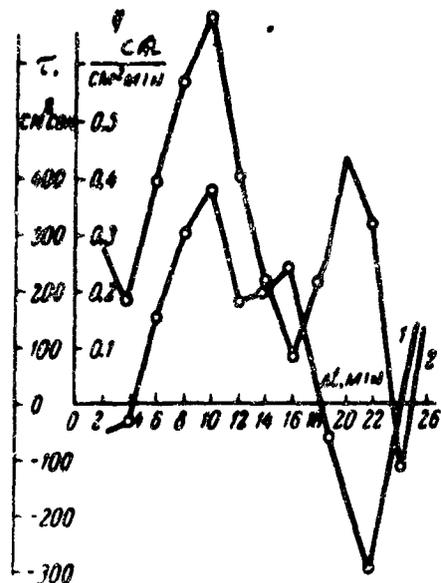


Fig. 18. Variation in time of friction stress (1 -  $\tau \sim U'W'$ ; 30 June 1960) and heat flux (2 -  $q \sim \theta'W'$ ; 5 July 1960).

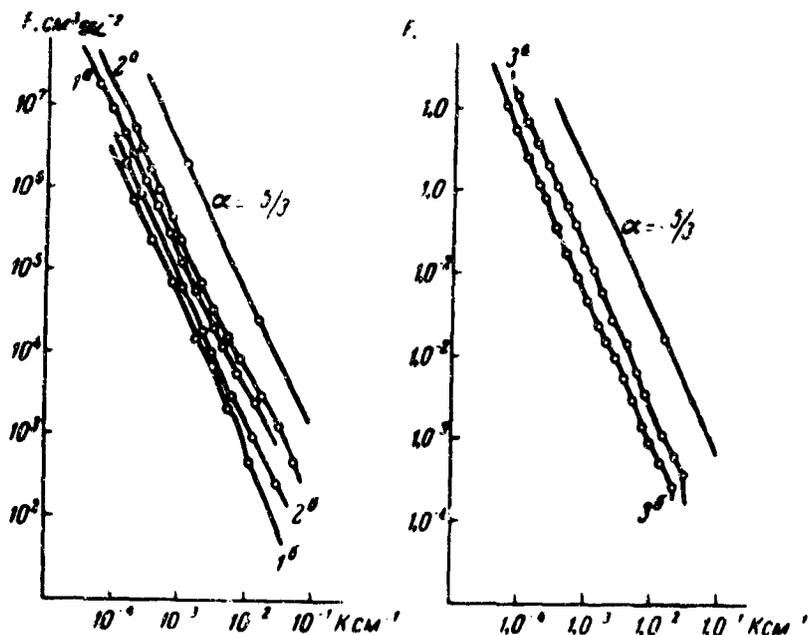


Fig. 19. Dependence of spectral density of energy of pulsations of horizontal and vertical components of wind speed and of pulsations of temperature on wave number  $k = \frac{\omega}{U}$

1a -  $U'$ ,  $Ri = +0.0010$ ; 1b -  $U'$ ,  $Ri = +0.9978$ ; 2a -  $W'$ ,  $Ri = -0.0323$ ; 2b -  $W'$ ,  $Ri = +0.6376$ ;  
3a -  $\theta'$ ,  $Ri = -0.0208$ ; 3b -  $\theta'$ ,  $Ri = +0.013$

In Fig. 16a, there is presented a correlation function, obtained by measuring of horizontal pulsations of wind speed at the 75 m level. In this example the horizontal dimension of heterogeneities at the level of measurements, determined by the drop of the correlation function to zero, amounts to about 200 m. In Fig. 16b, the change in turbulent energy with height is presented. In this case turbulent energy per unit of mass of air increases with height, as it amounts to 1 - 3 m<sup>2</sup>/sec<sup>2</sup> at the 100 to 500 m levels and 3 to 5 m<sup>2</sup>/sec<sup>2</sup> at 200 to 300 m.

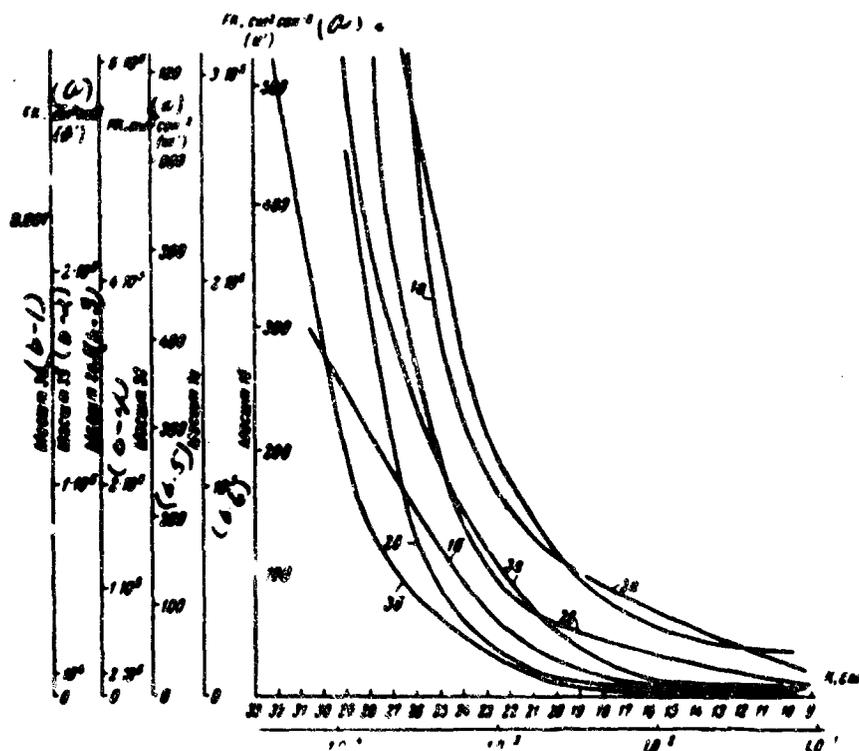


Fig. 20. Dependence of energy of the pulsation of temperature of the horizontal and vertical components of wind speed on the frequencies.

1a - U', R1 = +0,0013; 1b - U', R1 = +0,0079; 2a - V', R1 = -0,0326; 2b - W', R1 = -0,0029;  
2c - W', R1 = +0,0536; 3a - φ', R1 = -0,0209; 3b - φ', R1 = +0,0131

KEY: (a) cm<sup>2</sup>/sec<sup>2</sup>; (b-1) Scale 3a; (b-2) Scale 3b; (b-3) Scale 2a, b; (b-4) Scale 2c; (b-5) Scale 1a; (b-6) Scale 1b.

Figs. 17 - 20 illustrate complex measurements, made on the tower by L. R. Tsvang, S. L. Zubkovskiy, V. N. Ivanov, et al. by means of a micro-thermometer, "bianemovans" correlograph and frequency analyzer of spectra.

In Fig. 17, 18 there are given variations in time of dispersions of the pulsations (energies) of horizontal and vertical components of wind speeds and of

the temperature (Fig. 17), heat fluxes and friction stress (Fig. 18), drawn through the points, taken from corresponding recordings of measurements made every two minutes with an averaging for each 100 sec. In Fig. 19 the presented dependency (determined for different conditions of stability (Ri)) of the spectral density of energy of the pulsations  $\vartheta'$ ,  $U'$ ,  $W'$  on the wave number ( $k = \frac{U}{\omega}$ ), is plotted on a logarithmic scale. The corresponding graphs show that at the measured level (310 m) just as in the layer immediately above the soil and in the free atmosphere [59, 60], power function of spectral density of the pulsations of a frequency with exponent of a power  $\alpha = -5/3$ , derived from the Kolmogorov — Obukhov's "2/3" law.

If the spectral density of the energy of the pulsations is presented graphically in coordinates  $F_k$  and  $\log, k$ , then the corresponding curve (Fig. 20) shows the distribution of turbulent energy by the range of the wave numbers. A comparison of these graphs with results of other measurements in surface layer [59, 60] indicates the displacement with height of the maximum of energy of pulsations  $\vartheta'$ ,  $U'$ ,  $W'$  in region of lower frequencies; this is explained by the increase with height of scales of the dynamic turbulence and by decrease of the number of convective flows.

### 3. Centralized Control Management of Measuring Complex and Programming of Measurements

The recording of measurements and monitoring of operating conditions of measuring schemes in the complex of automatic meteorological measurements on lofty tower are centralized.

The recorders/ the converting and switching devices, et al, are installed in panels, which are reduced to a stand (Fig. 21). Control (switching, monitoring and adjustment of feeding and operating conditions of the measuring schemes, recorders, converters and switching devices) will be made from central panel.

In the stand and on the panel for conveniences in operating the apparatus the grouping of instruments according to systems of measurements (gradient and structural) and according to the parameters (Fig. 22) being measured has been made.

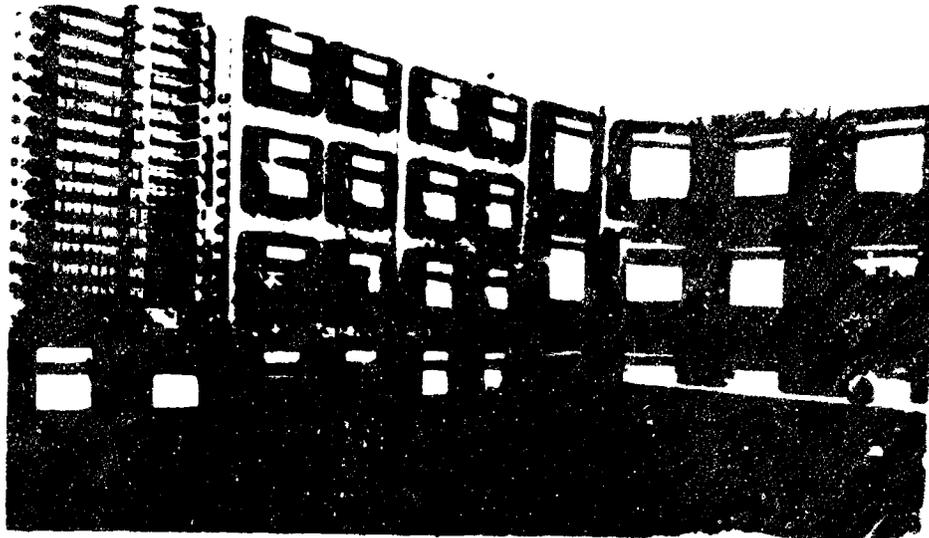


Fig. 21. General view of stands for high-tower recording instruments (left and right views).

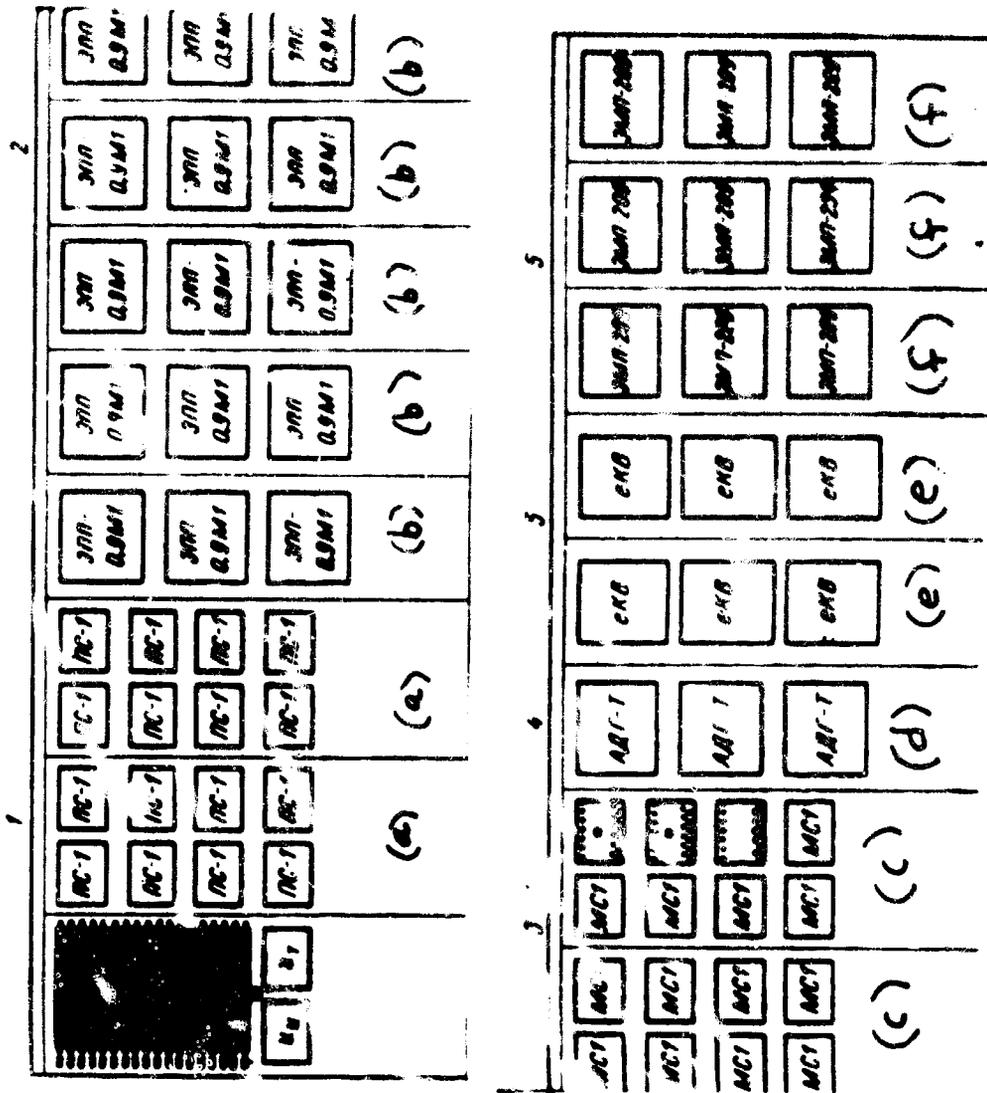


Fig. 22A. Development of stand of recorder-measuring complex of High tower.

- 1 — measurement of wind speed; 2 — structural measurements (M-27);
- 3 — measurement of humidity; 4 — measurement of temperature; 5 — radiation measurements; 6 — structural measurements.

KEY: (a) P3; (b) EPP-0.9MI; (c) MSl; (d) ADC-T; (e) EKV; (f) EKP-209.

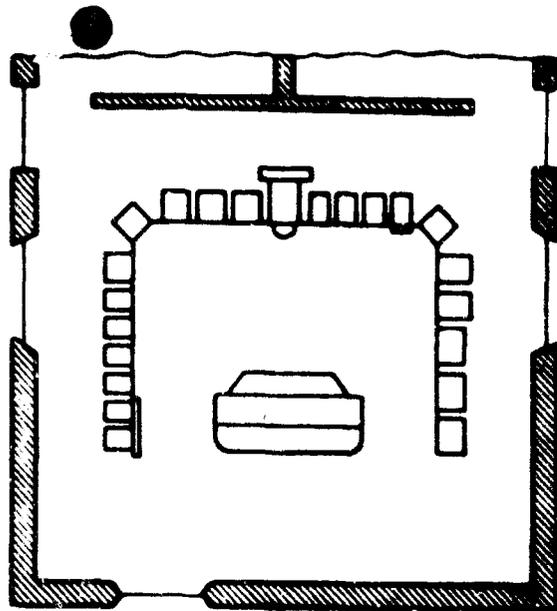


Fig. 22B. Plan of stand hall.

From the central panel there is realized the monitoring on the operating conditions feeding of measuring schemes and the recording of the measured parameters, and also communication with all levels of tower during operations on it (for example, during calibration of sensing units, et al.). On central panel there are introduced starting panels for single and complex connection of the recorders, converting and switching devices monitoring instruments, et al.

In initial variant on panel there is realized cell (toggle switch) switching in and turning off of recording complex. In the future the starting panels should be replaced by a master programming device by automatically controlled switching on of measuring and recording circuits according to the given program of measurements.

There is possible selector communication between the director of experiment, located at central panel, and collaborators on operating platforms of tower (for example, during production of experiments, calibration and control check of data units on tower).

The simultaneous recording of measurements of sensing units from all four verticals of tower is technically cumbersome and complicated; at the same time the scheme measuring lines and current expended on them increases and becomes more complicated.

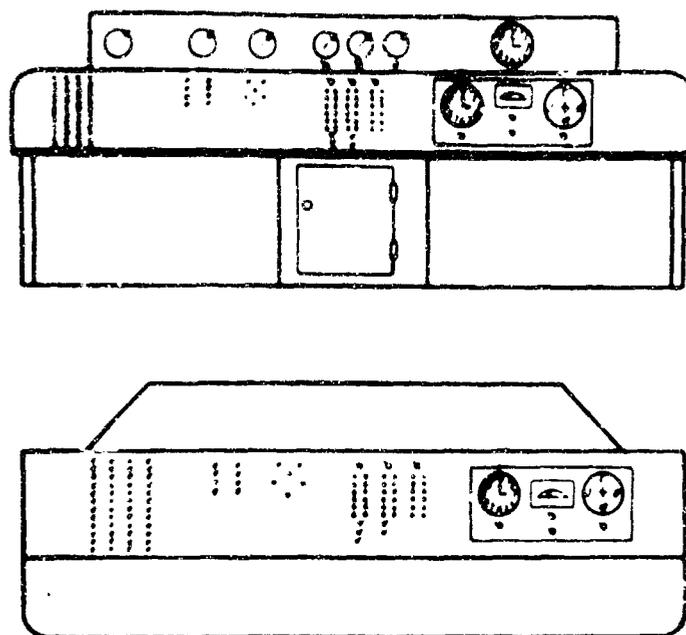


Fig. 22C. Control panel.

In order to ascertain the representativeness of measurements on tower in any one direction there have been made investigations of aerodynamic field along towers; these have shown that a vortex region and vestige of turbulence exists beyond body of tower, this limits its operating sector to  $240^\circ$ . The wind direction within the limits operating sector at distances from the location of sensing units (7.5 m) remains undistorted. Distortions of field of speeds in the operating sector at distance of more than 10 m from balcony do not exceed the error of measurement of wind speed by sensing units of photopulse anemograph. The effect of fixtures in the operating tower platforms with bracings and guard rails, rack winches on the lines of flow in the flow around the tower at distance of location of sensing units (7.5 m) is not significant.

In complex of measurements on the tower there has been adopted the principle of measuring on one windward side (vertical) which makes it possible to reduce recording apparatus by four times to reduce the power supply, and also the area, occupied by the recording apparatus; this correspondingly simplifies the measuring and power schemes.

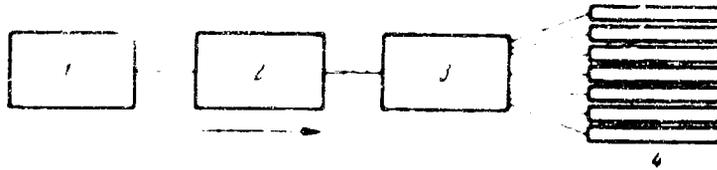


Fig. 23. Block diagram of programming of measurements.  
 1 -- assigning device; 2 -- decoder; 3 -- command block (electronic model); 4 -- measuring schemes.

At present in the complex of automatic meteorologic measurements on high tower take there has been adopted a 24-hour series recording of the chief meteorological parameters: temperature, average speed and direction of wind, humidity, et al. A frequent reading taken from measurements on tapes or graphs recording instruments requires a great expenditure of time and labor. The automation of processing of recording of measurements is still a complex problem and restricts the readings of the data to routine observation hours; the data between the routine observation hours remains unused.

It is expedient that certain meteorological measurements are not made at routine observation hours but rather with respect any one process occurring in the atmosphere (movement of fronts, increasing instability, associated with causes of a dynamic or thermal nature, et cetera). Such nonroutine measurements are essential for investigations on particular meteorological phenomena.

It follows from this necessity of introducing in certain cases the programming of measurements, i.e., including measurements of parameters at definite periods of time at any one or any combination of levels, as required by a particular investigator or according to a program of measurements requested by a individual user.

In a possible fundamental block diagram of automatic programming of measurements (Fig. 23) program of measurements on punched or magnetic tape is introduced into the assigning mechanism, the signals from which proceed to the decoder. The appropriately deciphered and grouped programs for the decoder signals proceed to the command block, from which they proceed to measuring channels by switching in or unswitching the corresponding measuring schemes.

In working out a programming of measurements one should proceed from distinction of apparatus of passive measurements with those apparatuses of an active measurement with a self-adjustable program on the basis of assumed or established laws of the natural processes.

#### 4. On Processing Data Derived from the Measurements

Data derived from measurements in the complex of the high tower are processed at present toward reading values off of the recording traces of measuring instruments at adopted routine observation times with an averaging of data for a 10-minute interval; processing of data from measurements according to adopted measurements in the investigations of a particular meteorological element.

The occasionally used electro-mechanical system-perforator -- sorter-tabulator does not possess adequate possibilities of analysis; there remains unsolved the very important problem of automatic transfer of data of measurements from the sensing units or from the recording traces on recording instruments onto punched card or punched tapes; for certain investigations it is expedient to use electronic-computers during the processing of materials.

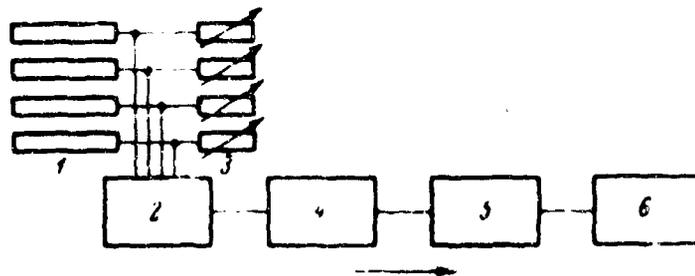


Fig. 24. Block-diagram of programmed punch-card machine.  
1 -- sensing units; 2 -- modulator; 3 -- recorders;  
4 -- encoder; 5 -- master unit; 6 -- punch-card machine.

In the possible scheme of a programmed punching (Fig. 24) signals of the pulse sensing units or quantised (for example, in circuit of pulse modulator) continuous signals from the sensing units of continuous operation proceed in parallel

to circuit of registration to the coding mechanism. From the coding device the grouped signals through the returning master unit are fed into an automatic punching-machine or magnetic recording.

A statistical analysis of structural (pulsational) measurements can be made both by their direct processing in correlators and also with use of radio-engineering circuit "correlator-meters" spectra analyzers et al., in which necessary sequence of mathematical operations is made directly over signals from sensing elements [5, 6, 32, 59, 60, 73]. The averaging in the circuits of analyzers of statistical characteristics it is desirable to make after an interval of time, greater than the period of the very lowest frequency of investigated range; for the optimum interval of temporal averaging is adopted in such a way that the result is statistically stable.

For control of measurements there is introduced a check of their technical (instrumental) and geophysical authenticity. The assurance of technical (instrumental) authenticity of the measurements involves a systematic control of the operation of apparatus in accordance with specifications of its operation, its periodic calibration, a verification by nomograph, technical analysis of the measurements. The geophysical — authenticity is assured strict fulfillment of instruction in methodology in reading off the measurements from the recording traces, technical check and physical analysis of the data from the measurements.

Authenticity of measurements is limited: by the accuracy of measurements (accuracy of sensing element, error of recorder, connecting lines, intermediate elements); representativeness of interval of averaging, identity of measuring circuits (sensing elements at different levels).

Identity of sensing elements mounted on one vertical, is extremely important for obtaining of good profiles. Deviation of the accuracy of measurements between adjacent sensing elements should not exceed 0.1 m/sec for the speed and 0.1°C for the temperature.

## Conclusions

1. The Institute of Applied Geophysics complex of automatic meteorological measurements in the lower 300-meter layer of atmosphere, based on high-altitude tower of the Institute, is essentially an automatic geophysical observatory developed and designed for the solution of a number of theoretical and applied problems, associated with meteorological conditions and physical processes in the lower layer of atmosphere.

The high-altitude tower, equipped with complex of measuring apparatus, serves like probe, thrust into an atmospheric layer. The organization and development of a network of such "probes" can considerably literally and figuratively raise the level of atmospheric investigations and operational meteorological service.

2. The development of complex of automatic meteorological measurements in the lower 300-meter layer of atmosphere will be conducted towards developing a system of gradient and structural (pulsational) measurements.

3. The development and utilization of complex of automatic meteorological measurements in the lower 300-meter layer of atmosphere on high-altitude tower will involve a number of important problems, a portion of which are solved at present, and the solution of other problems is matter of the immediate future.

4. Present problems in developing the complex of automatic meteorological measurements on high-altitude tower are: a subsequent development and utilization of automatic measurements of humidity by a spectrum (radiation) method; development and utilization in experimental models of a stationary complex of structural (pulsational) measurements; development of system of immediate punch-card perforation of results of measurements, a remote-control recorder of cloudiness, a visibility recorder, precipitation and icing recorders and an "icing-graph".

Automation of determining cloudiness by a 10-point scale, by levels (high, middle, low) and structure can be realized by an installation, superposing a

spherical mirror, in which the cloudiness of the celestial hemisphere is reflected [3], and a television transmission of this image to a recorder with the fixation of it on the image visualization tape specially developed with the use of principles, for example, of a phototelegraphic apparatus.

As the basis of this scheme of photographic method is one of the most convenient in a systematic study of movement and development of clouds. It gives a clear representation of character of cloudiness in various parts of sky, its variation and amount of cover over the celestial arch. By having successive photographs of the cloud-cover, it is possible to quantitatively to determine how it or other clouds develop in time and how its linear dimensions and area varies.

The proposed method excludes a subjective evaluation of the cloud-cover and makes it possible to obtain more reliable objective data and at the same time not only qualitative, but also quantitative idea of the location and forms of the cloud-cover over the celestial arch code. Knowledge of angular coordinates and heights of the cloud-cover provides the possibility of quantitatively estimating the rate of its speed movement, its development which is specially important during investigations of a rapidly changing cloud-cover.

The registration of visibility in the complex of the tower can be realized both at all heights of the lower 300-meter layer of atmosphere (vertically), and also on horizontal and oblique visibilities. Acceptable variants of the solutions of this problem are available in works [12, 16].

The registration of precipitation from registrations of their beginning, termination and intensity can be realized by means of existing instruments and those used in special investigations concerned with precipitation measurement (rain gages, et cetera).

Especially the expediency of development of an icing recorder and an "icing-graph" must be mentioned, inasmuch as on tower and in general on lofty structures during autumn and winter there is observed heavy icing. The study and action of icing on construction is of great practical interest.

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