MINISTRY OF EDUCATION OF RYSSIAN FEDERATION

RUSSIAN STATE HYDROMETEOROLOGICAL UNIVERSITY

GRIGOROV N.0.

METEOROLOGICAL MEASUREMENTS

LECTURE SUMMARY

For Students of Meteorological Department

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Meteorological measurements. Lectures summary. For students of meteorological department, taught in English.

The summary contains information about meteorological measurements, lectured to students of meteorological department for two semesters. The main attention is drawn to methods to measure temperature, humidity, wind parameters, atmospheric pressure and other meteorological values. Russian devices М-63м, ИВО-1м, ФИ-1 and other are described too. The short information about future development of meteorological devices is given in the end.

As the summery is used by Russian students, the vocabulary is placed in the end of every lecture.

Метеорологические измерения. Конспект лекций. Для студентов метеорологического факультета, обучающихся на английском языке.

Конспект содержит сведения о метеорологических измерениях, излагаемые студентам метеорологического факультета в течение двух семестров. Наибольшее внимание уделяется методам измерения температуры, влажности, параметров ветра, атмосферному давлению и других метеорологических величин. Описаны также российские приборы М-63м, ИВО-1м, ФИ-1 и другие. В конце рассказывается о перспективах развития метеорологических измерений.

Поскольку конспект используется в основном, русскими студентами, то в конце каждой лекции помещен небольшой словарик незнакомых слов.

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INTRJDUCTION

In this course "Meteorological Measurements" we are going to study methods of meteorological measurements and the main principles of measure devices actions. The course is lectured at meteorological faculty, so we'll study meteorological devices. But physical principles of these devices action are the same for all the devices, measuring the value. That's why you'll easily understand hydrological devices, if necessary.

The course is read during two semesters. In the first semester we'll study only the main methods of meteorological measurements (lectures 1-15). The second semester (lectures 16-28) is devoted to meteorological devices themselves. The last lecture (lecture 28) is devoted to the prospects of meteorological measurements in future.

Now let's speak about the meteorological measurements themselves. Nowadays an observer must measure a lot of values at the same time. These are air temperature, relative humidity, atmospheric pressure, wind speed and wind direction, cloud base altitude, meteorological visibility range and many others. Take into account, that many values must be measured in different points. Such measurements are difficult to be done by person. That's why modern meteorological devices are, as a rule, *remote devices*. Let's distinguish two groups of remote devices.

The remote device of the **first group** is the device with the sensor placed in the point of measurements. It is connected by wire (or another connection) with the special block (the control panel) placed inside a room.

The remote devices of the **second group** have no sensor itself. Sometimes they are called *locators*. We'll distinguish *active* and *passive locators*.

Active locators are the devices that emit signal to the point in the atmosphere, we are interested with. The signal is reflected by the air parcel and comes to the *receiver*. This reflected signal depends on meteorological values in the parcel. So these values can be measured. There are laser locators (see lecture 28), sound locators, electromagnet locators (MRL-2, MRL-5 and others).

Passive locators don't emit signal. They receive a signal, emitted by a body, or by air parcel. Parameters of this signal depend on the meteorological values of the parcel, so these values can be known. For example, electromagnet radiation, emitted by any body in infrared range, depends on body temperature. By this method temperature of far stars can be measured.

To measure meteorological values is only the part of the problem. Another part is to remember and to write the information. Then this information must be analyzed and transmitted to line connection to a user. You understand, such equipment can't be called "device" because it is a complex. We'll call them *information-measuring systems.*

So, to begin with we'll study methods to measure meteorological parameters. The most important parameters are temperature, air humidity, atmospheric pressure and wind parameters.

Chapter 1

TEMPERATURE MEASUREMENTS

Lecture 1.

1. HEAT INERTIA OF THERMOMETERS.

The heat inertia is a property of thermometers. Due to this property thermometers perceive the surrounding temperature with an inhibition.

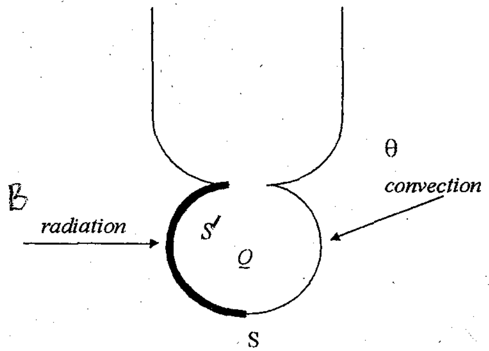

Fig. 1 Thermometer's body and heat fluxes.

The heat inertia is inherent only to thermometers, containing thermometer's body (e.g. bulb). Suppose, there is a thermometer - mercury thermometer, for example (see fig. 1). Let's denote heat amount in the bulb as Q; the bulb's surface as S; the surrounding temperature as Θ; the bulb's temperature as T; the coefficient of heat exchange between the bulb and surrounding as α; the net radiation fluxes to the bulb as B; the part of the bulb's surface, irradiated by these fluxes as S'; and time as τ.

The equation for heat exchange between the bulb and surrounding:

$$\frac{dQ}{d\tau} = \alpha \cdot S(\theta - T) + BS' \qquad (1.1)$$

We know, that:

$$dQ = mc \cdot dT,$$

where m is bulb's mass; c is the specific capacity of bulb's material.

Then: $$\frac{mc}{\alpha \cdot S} \cdot \frac{dT}{d\tau} = \theta - T + \frac{BS'}{\alpha \cdot S}.$$

Let's denote:

$$\frac{mc}{\alpha S} = \lambda \quad \text{and} \quad \frac{BS'}{\alpha S} = R,$$

Herefrom we obtain:

$$\lambda \cdot \frac{dT}{d\tau} = \theta - T + R. \qquad (1.2)$$

Let's assume:
1) B = const, so R = const.
2) $\theta = \theta_o + \gamma\tau$, where γ is a speed of temperature change.
The initial condition for the equation (1.2) will be the following:

$$T_{\tau=0} = T_0.$$

Pay attention - values γ and λ are constant for the measurement time range (about 10 - 15 min., not more). To tell the truth, α depends upon the wind speed, this dependence can be expressed by the formula:

$$\alpha = a + b\sqrt{\rho \cdot V}, \qquad (1.3)$$

where ρ is air density, a and b are constants. But during 10 - 15 min the wind speed V can't change enough to be taken into account.
To solve the equation (1.2) let's change the variable:

$$x = T - \theta = T - \theta_0 - \gamma \cdot \tau$$

Then we may write:

$$T'_\tau = (x + \theta_0 + \gamma\tau)'_\tau = \frac{dx}{d\tau} + \gamma$$

$$\frac{dT}{d\tau} = \frac{dx}{d\tau} + \gamma .$$

Then the equation (1.2) can be written as:

$$\lambda \cdot \left(\frac{dx}{d\tau} + \gamma \right) = -x + R .$$

Or:

$$\lambda \cdot \frac{dx}{d\tau} = -x + R - \gamma\ \lambda$$

Separating the variables, we obtain:

$$\frac{dx}{x - R + \gamma\ \lambda} = -\frac{d\tau}{\lambda} .$$

And, integrating from x_o to x, we can write:

$$\int_{x_0}^{x} \frac{d(x - R + \gamma\ \lambda)}{x - R + \gamma\ \lambda} = -\int_{0}^{\tau} \frac{d\tau}{\lambda} .$$

Or, taking integrals:

$$\ln \frac{x - R + \gamma\lambda}{x_0 - R + \gamma\lambda} = -\frac{\tau}{\lambda} .$$

Then, getting over from x to T:

$$T - \Theta = (T_0 - \Theta_0 - R + \gamma\ \lambda) \cdot e^{-\frac{\tau}{\lambda}} - \gamma\ \lambda + R \qquad (1.5)$$

This is the equation we wanted to derive. Let's discuss it. The equation is difficult enough to analyse it at all. First of all we'll consider various special cases the equation can be applied to.

1. Let's set $\gamma = 0$ and $B = 0$. Herefrom it follows that Θ = const and $R = 0$. Then:

$$T - \Theta = \left(T_0 - \Theta\right) \cdot e^{-\frac{\tau}{\lambda}} \qquad (1.6)$$

It also can be represented in graph form (see fig.1.1):

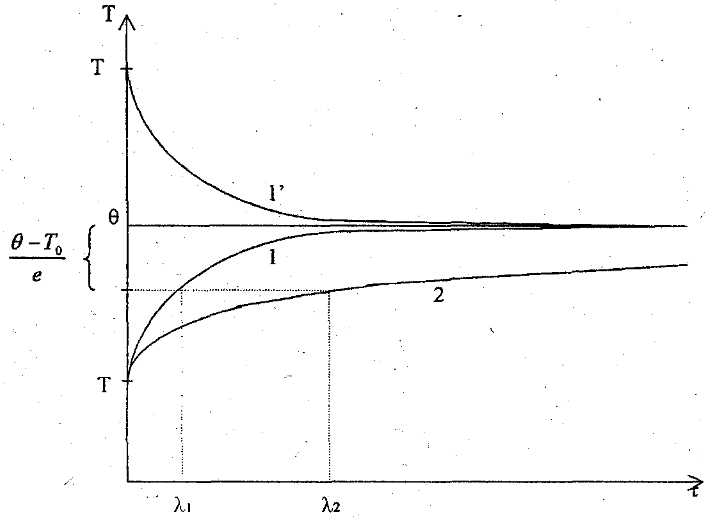

Fig. 1.1.

The form of this curve depends upon λ. Therefore, λ is an important parameter. Let's consider its dimension. The exponent τ/λ must be undimensional. Thus, the dimension of λ is the same as the dimension of τ (time). On the other hand, λ = const for certain thermometer. Thus let's call λ the thermometer heat inertia coefficient. Sometimes it is called ***lag coefficient***. One can easily understand, if $\tau = \lambda$, $T - \Theta = (T_0 - \Theta) \cdot e^{-1}$.

The thermometer lag coefficient is the time range, during which temperature difference between thermometer and surrounding would be decreased by e times.

Any observer would like to have thermometers with low values λ. Let's consider how to achieve this. To do so let's recall:

$$\lambda = \frac{mc}{\alpha \cdot s}$$

Hence, to make λ low, **m** (the mass of bulb) must be low, **c** must be low too, but **S** (the bulb's surface) must be large, and α must be high. But as we've mentioned $\alpha \propto \sqrt{\rho \cdot V}$, where ρ is density of surrounding, V is the speed of its motion (wind's speed). Thus, it's desirable to make the high value of V, or to aspirate the thermometer. On the other hand, when ρ is high (e.g. we measure water's temperature), α is high too, and λ is low.

2.Let's set B = 0, $\Theta = \Theta_0 + \gamma \cdot \tau$

Then:

$$T - \Theta = (T_0 - \Theta_0 + \gamma \lambda) e^{-\frac{\tau}{\lambda}} - \gamma \lambda \qquad (1.7)$$

From the equation one can see that when $\tau \to \infty$, $T - \Theta \to -\gamma \cdot \lambda$. Hence the sign of difference $T - \Theta$ depends upon the sign of γ. When $\gamma > 0$ (it means, surrounding temperature rises), $T - \Theta < 0$. On the contrary, when $\gamma < 0$ (Θ decreases), $T - \Theta > 0$ (but when $\gamma < 0$ only!).

Let's represent this dependence in graph form (see fig.1.2).

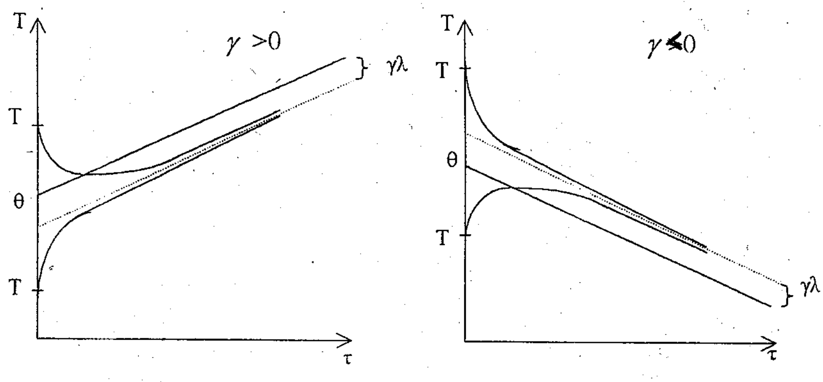

Fig.1.2

Pay attention - the thermometer's temperature always *lags behind surrounding's temperature*!

The value $(T - \Theta)$ doesn't depend on T_0. So, would T_0 more or less than Θ_0, it's not important for ultimate effect.

When $T_0 > \Theta_0$ and $\gamma > 0$ (or when $\gamma < 0$ and $T_0 < \Theta_0$) the curve T (τ) has an extremum. But in the extreme point T = Θ ! I would like you to prove this yourself.

3.Let's put $\gamma = 0$ and $B \neq 0$. Herefrom it follows $R \neq 0$. But R is always positive value ($S' > 0, \alpha > 0, S > 0$).

Then the equation will take a form:

$$T - \Theta = (T_0 - \Theta - R)e^{-\frac{\tau}{\lambda}} + R \qquad (1.8)$$

When $\tau \to \infty$ $T - \Theta \to R$, that is always positive. To make this value low it's necessary to decrease B (placing the thermometer into shadow) and to increase α (aspirating the thermometer).

4. In reality Θ can fluctuate. We'll consider only right-angled function $\Theta(\tau)$, as plotted here:

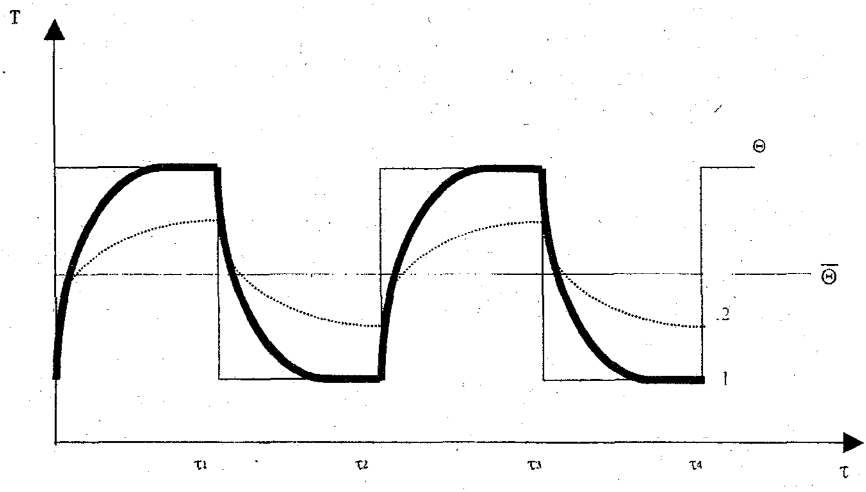

Fig. 1.3

The thermometer's temperature will oscillate too, but when λ is low (curve 1), the difference T- Θ is low too. It allows us to measure all fluctuations. On the opposite case, when λ is high (curve 2) the thermometer's temperature will make low occupations round $\overline{\Theta}$. So, it's feasible to measure $\overline{\Theta}$.

Real meteorological thermometers have to be made according to specification:

$$\gamma\lambda < \Delta t. \quad (1.9)$$

where Δt is a possible permitted mistake (about 0.1^0 for meteorological measurements).

So, we can write:

$$\lambda < \frac{\Delta t}{\gamma}. \quad (1.10)$$

Here γ is a maximum possible rate of temperature change.

VOCABULARY

Heat inertia – тепловая инерция
Inhibition – задержка
Inherent – свойственный
Flux – поток света, радиации
Specific capacity – удельная теплоемкость
Lag coefficient – коэффициент тепловой инерции (дословно – коэффициент запаздывания)
Aspirate – аспирировать, обдувать
Shadow – тень
Lag behind – отставать

2. RESISTOR TEMPERATURE SENSORS.

Let's take a resistor. When temperature rises, the speed of molecule movement rises too. Thus, it's more difficult for electrons to move through such surroundings. A current via resistor falls. A value of resistance rises. It is known from experiments, the dependence of a resistance upon temperature is following:

$$R = R_o(1 + \alpha \cdot t) \tag{2.1}$$

Here R is resistance, t is temperature in degrees centigrade, R_0 is the resistance when $t = 0^0 C$ and α is a resistant coefficient of temperature. Let's plot this dependence (fig 2.1, curve 1).

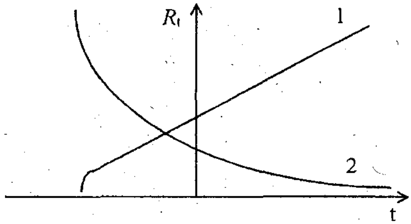

Fig.2.1. The dependence R(t): 1 - for thermoresistances, 2 - for thermistors.

The value α is different for different conductors, but the order of their magnitude is about $10^{-3} K^{-1}$. Certainly, the resistor sensors must be made with materials of high α value. Such as copper ($\alpha = 4.28 \cdot 10^{-3}$ K^{-1}), platinum ($\alpha = 3.94 \cdot 10^{-3}$ K^{-1}) and others. Some materials, *constantan* for instance, has $\alpha \approx 0$. They are useful for measuring equipment too. (But not as sensors, of course).

Let's consider some other materials - semiconductors. As you know, electrons within semiconductors can move from valence zone (low level) to zone of conductivity (high level). Of course, it may be only when the energy difference between these levels is not high. An electric field can cause such a passage, then the material becomes a conductor. But the temperature rising can cause it too! Thus when temperature rises the resistance of semiconductor decreases (curve 2, fig. 2.1). Such temperature sensors (semiconductors) are called ***thermistors***.

Let's pay attention on the following features of semiconductor temperature sensors (thermistors):

1.The absolute value of α for them is higher, than for resistance.

2.For the thermistors $\alpha < 0$ (R falls when temperature rises).

3. α isn't constant, it depends on temperature (the dependence isn't linear).

4.The dependence R(t) isn't stable. It does vary with time. It means that such kind of sensors can be adopted only once - for example, in radiosounds.

3. MEASURING BRIDGE CIRCUITS.

To measure a resistance (e. q., thermoresistance) we may use measuring bridge circuits. Now we will consider such circuits.

Let's take two variable resistances, which are connected as follows:

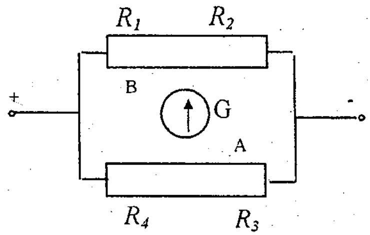

Fig.2.2.

The measuring instrument G may show a current **i**. When we move handles of resistor, the current changes. It can either be greater than zero ($i > 0$) or less than zero ($i < 0$) or equal to zero ($i = 0$).

Let's consider the latter case, $i = 0$. For the sake of convenience we'll redraw the circuit (fig.2.3).

It's easy to see from the circuit, that if $i = 0$, the potential at the point A is the same as that at the point B. So, the voltage drop over the resistor R1 is the same as the voltage drop over R4. On the other hand, the current i1 in R1 is equal to the current in R2, and the current i2 in R4 is equal to the current in R3. It allows us to write the equations:

$$i_1 \cdot R_1 = i_2 \cdot R_4$$

$$i_1 \cdot R_2 = i_2 \cdot R_3$$

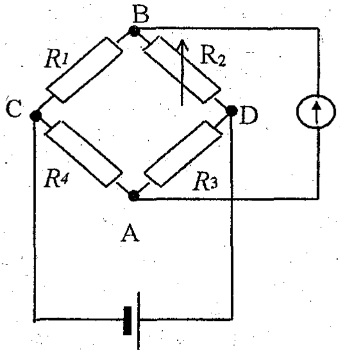

Fig.2.3.

Let's multiply the left part of the first equation by the right part of the second one, and the right part of the first equation by the left part of the second one:

$$i_1 \cdot R_1 \cdot i_2 \cdot R_3 = i_1 \cdot R_2 \cdot i_2 \cdot R_4$$

or, cancelling products $i_1 \cdot i_2$:

$$R_1 \cdot R_3 = R_2 \cdot R_4. \tag{2.2}$$

This is the equation of the *balanced bridge circuit*. Using it, we may determine one of the resistance, e.q. R1, when the others - R2, R3 and R4 - are known. Such a circuit is called balanced bridge circuit.

But in the other cases - when $R_1 \cdot R_3 \neq R_2 \cdot R_4$, the circuit isn't balanced. Then $i \neq 0$. Let's determine its value. To do so let's recall the equivalent generator theorem and present it in form of following equation:

$$i = \frac{U_{AB}}{R_{SC} + R_g}. \tag{2.3}$$

where U_{AB} is the voltage between points A and B, R_{sc} is the resistance between points A and B while short-circuited (it means that the battery is replaced with wire, R_g is the resistance of measuring instrument - e.g., galvanometer).

Now, let's find the expression for the voltage U_{ab}. It is:

$$U_{AB} = \varphi_A - \varphi_B, \tag{2.4}$$

where φ_A and φ_B are the potentials at points A and B. According to Ohm's law:

$$\varphi_A = \frac{UR_3}{R_3 + R_4}, \tag{2.5}$$

where U is the electromotive force (EMF) of the battery.
It can be easily seen from the figure 2.4:

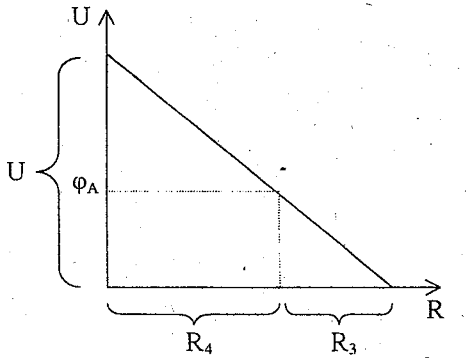

Fig.2.4

The small triangle and the large one are similar to each other (see fig.2.4.)
By analogy with (2.5) we can write:

$$\varphi_B = \frac{UR_2}{R_1 + R_2}. \tag{2.6}$$

Then:

$$U_{AB} = U\left(\frac{R_3}{R_4 + R_3} - \frac{R_2}{R_1 + R_2}\right) = U\frac{R_1R_3 - R_2R_4}{(R_1 + R_2)(R_3 + R_4)}$$

Suppose, $R_2 = R_3 = R_4 \equiv R$ and $R_1 \approx R$.
Taking it into account, we can write:

$$U_{AB} = U\frac{R_1 - R}{4R}. \qquad (2.7)$$

Now let's derive the expression for Rsc. For this case the circuit may be drown as:

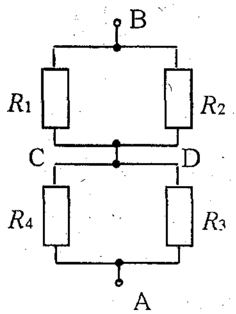

Fig.2.5

And herefrom we can write:

$$R_{SC} = \frac{R_1 \cdot R_2}{R_1 + R_2} - \frac{R_3 \cdot R_4}{R_4 + R_3} \qquad (2.8)$$

These expressions allow us to obtain the formula for i:

$$i = U\frac{R_1 - R}{4 \cdot R\left(R + R_g\right)}. \qquad (2.9)$$

Herefrom R_1 can be calculated, if the current i is measured. Of course, the values U,R and Rg must be known.

Thus we can use disbalanced bridge circuits as well as balanced ones to measure the resistance.

VOCABULARY

Remote - дистанционный
Wide-spread - широко распространенный
Wire – провод
Connection - соединение
Transducer - преобразовать
Crowd - толпа
To resolve into components - разложить в ряд
Copper - медь
Platinum – платина
Semiconductors - полупроводники
Holes - дырки, отсутствие электронов
Thermistor - термистор /полупроводниковый датчик температуры/
Shortcoming - недостаток
Steady - стабильный
Circuit - схема
For the sake of - ради /чего-либо/
Voltage drop - падение напряжения

4. BALANCED RESISTIVE THERMOMETER

The temperature measurement can be made by balanced bridge circuit. To do so let's place a thermoresistor into any arm of circuit (see fig.3.1):

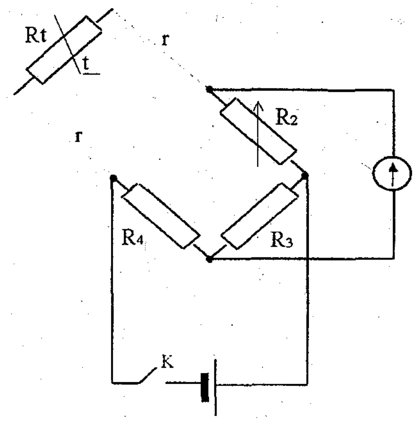

Fig.3.1. Balanced resistive thermometer.

To balance the circuit the variable resistor R2 can be used. According to equation:

$$R_t \cdot R_3 = R_2 \cdot R_4 \qquad (3.1)$$

any value of Rt (and consequently, temperature) corresponds to R2 . By such a method we can calculate the temperature:

$$R_0 \, (1 + \alpha \, t) \cdot R_3 = R_2 \cdot R_4 \, . \qquad (3.2)$$

So, we obtain:

$$t = \frac{1}{\alpha}\left(\frac{R_2 \cdot R_4}{R_3 \cdot R_0} - 1\right). \qquad (3.3)$$

All the values in this equation are known, including R2. Such a thermometer is called balanced resistive thermometer.

Now let's derive the expression for the sensitivity of that thermometer.

A sensitivity (S) of any device is a derivative of output value (Y) with respect to input value (X):

$$S = \frac{dY}{dX}.$$

According to this definition, we can write the expression for the sensitivity of balanced resistive thermometer:

$$S = \frac{dR_2}{dt}$$

Taking R2 from (3.2) and differentiating it, we have:

$$S = \alpha \frac{R_0 \cdot R_3}{R_4}. \tag{3.4}$$

Consequently, we can recommend two methods to increase the sensitivity of the thermometer:

1. To use a material with high α.
2. To use a circuit with high R2.

Now let's discuss sources of possible errors for this thermometer. We may point out two specific sources of errors with balanced resistive thermometer.

1. Heating of thermoresistor by current. The following methods can be recommended to shoot the error.

1.1. To reduce the current through thermoresistor, using low voltage of battery, or using a high value of thermoresistor resistance.

1.2 To use an aspiration of thermoresistor.

2. Variations of resistance of wires (r) connecting the thermoresistor with circuit. To shoot this possible error three-wire circuit can be used.(see fig. 3.2)

Let's compare it with two-wire circuit (see fig. 3.1) We may point that both of wires r in two-wire circuit (fig. 3.2) are in the same arm.

$$(R_t + 2r) \cdot R_3 = R_2 \cdot R_4 \tag{3.5}$$

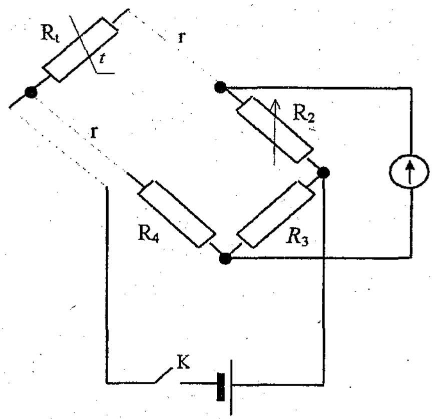

Fig.3.2 Three-wire circuit.

On the other hand, three-wire circuit (fig. 3.2) contains wires r in the different arms. On this basis we can write the equation for three-wire circuit:

$$(R_t + r) \cdot R_3 = R_2 \cdot (R_4 + r) \qquad (3.6)$$

This equation is more stable against variations of r than that for two-wire circuit.

Speaking about the third wire, one may notice - it's not important for equations!

5. FEEDBACK CONTROL SYSTEMS. AUTOMATICALLY BALANCED RESISTIVE THERMOMETER.

We have considered the balanced resistive thermometer. But it's not convenient to use it, because one must balance the bridge circuit. Could we automate this process? Yes, we can.

For this purpose *feedback control systems* are used. Let's consider them. The block-diagram for such a system is drawn on fig.3.3:

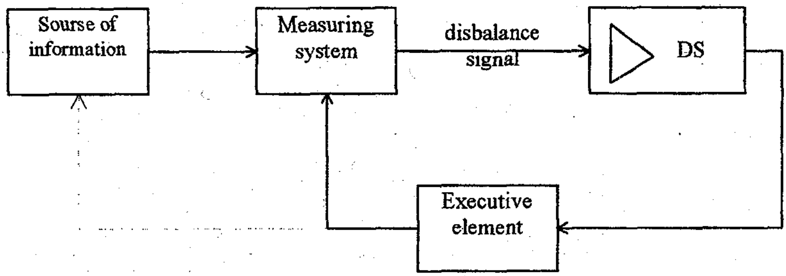

Fig.3.3. Block-diagram of feedback control system.

When *measuring system's* parameters don't correspond to information from a source, the disbalance signal appears. After amplification by *disbalance signal amplifier* (DSA) it comes to *executive element.* This element acts to a *measuring system*, changing its parameters. When these parameters become corresponded with information from a source, disbalance signal vanishes. The executive element finishes to operate. But then the information changes, disbalance signal appears again, the executive element starts operating and all the cycle is repeated. Thus, controlling system's parameters are always corresponding to information from source - e. q., to temperature.

But the another course is imaginable. The executive element may act to a source of information - for example to heat or to cool air in a volume. Our home fridge operates so.

Now let's consider the circuit of automatically balanced resistive thermometer (see fig. 3.4).

First of all we can see the bridge circuit - Rt - R3 - r2 - r1. It may be balanced by the variable resistor r1 - r2. When it's balanced, the voltage in measuring diagonal is equal to zero. But when the circuit isn't balanced, the voltage isn't equal to zero. Thus, amplifying signal comes to *reverse motor* (RM). It starts to move resistor r1 -r2 and to balance the bridge. It's easy to understand that reverse motor stops when the bridge becomes balanced because the voltage in measuring diagonal is equal to zero!

On the other hand, the reversal motion moves *paper recorder.* Consequently, we obtain the paper with the plot of temperature versus time.

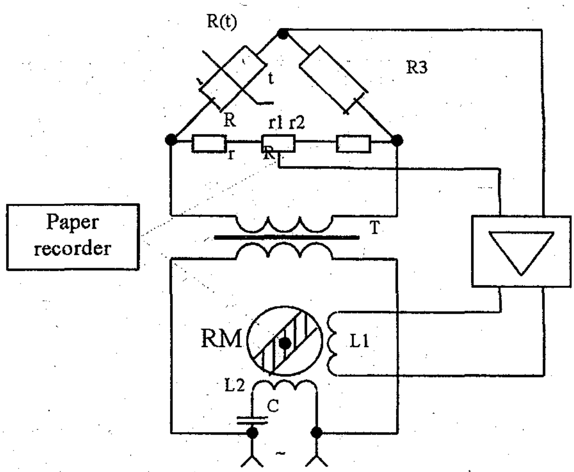

Fig.3.4. Automatically balanced resistive thermometer.

Such feedback control systems are widely used in measuring instruments.

VOCABULARY

Balanced bridge circuit – уравновешенная мостовая схема
Sensitivity - чувствительность
Output value – выходная величина
Input value – входная величина
Error - погрешность
To shoot the error – избавиться от погрешности
Three-wire circuit – трехпроводная схема
Feedback control system – следящая система с отрицательной обратной связью
disbalance signal – сигнал разбаланса
Amplifier – усилитель
Executive element – исполнительный элемент
Vanishes – исчезает, становится равным нулю
Operate – работать (о приборе, механизме)
Reverse motor – реверсивный двигатель
Paper recorder – самописец

Lecture 4.

6. DISBALANCED RESISTIVE THERMOMETER.

Disbalanced resistive thermometer (DRT) is constructed with bridge circuit. But there isn't a variable resistor in an arm (see fig.4.1).

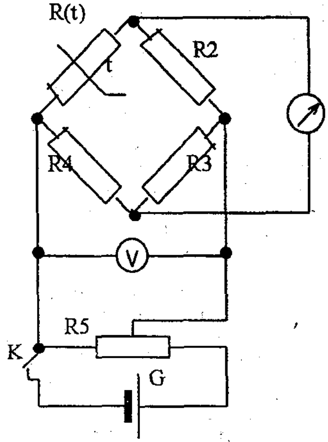

Fig.4.1

All the resistors (R2, R3, R4) are constant. Thus, the current i through the instrument G depends on Rt, and on temperature consequently. Let's recall the equation for current i. It is :

$$i = \frac{U \cdot (R_t - R)}{4R \cdot (R_g + R)}, \qquad (4.1)$$

where R is the value of resistance R2 = R3 = R4 = R,

U is the voltage in the feed diagonal,

Rg is the inner resistance of instrument G.

Substituting the expression for Rt to this equation, we obtain:

$$i = \frac{U \cdot (R_0(1 + \alpha \cdot t) - R)}{4R \cdot (R_g + R)}. \qquad (4.2)$$

Let's derive the equation for sensitivity of DRT. According to definition of sensitivity, one can write:

$$S = \frac{UR_0 \cdot \alpha}{4R \cdot (R_g + R)} \approx \frac{U \cdot \alpha}{4(R_g + R)}. \qquad (4.3)$$

It can easy be seen from this equation how we can increase the sensitivity of DRT. There is only one opportunity - to use a material with high α for sensor. The other imaginable opportunity - to use a battery with high U - can't be adopted! The error due to thermeresistor's heating by current would be high too.

Discussing sources of possible errors, we can point the following.

1.Heating of thermoresistor by current.

2.Heating of measurement instrument G by current.

3.Variations of resistance of wires, connecting the thermoresistor with circuit.

4.Variations of voltage U in the feed diagonal.

To shoot the errors (1), (2) and (3), we can use the same methods as those being used for balanced resistive thermometer. To shoot the fourth error we have to control the voltage U, by voltmeter V for example. The voltage divider R4 gives the opportunity to vary the voltage U, when necessary.

7. DIFFERENTIAL RESISTIVE THERMOMETER.

Differential resistive thermometer is used for measurement temperature difference between two points. It can be made by using the bridge circuit (fig. 4.2).

Here Rt1 and Rt2 are the thermoresistors. They have absolutely equal values when $t_1 = t_2$. But, if $t_1 \neq t_2$, $R_{t1} \neq R_{t2}$ consequently, and the bridge becomes disbalanced. One can construct a balanced differential resistive thermometer taking variable resistance R3 or R4, and a disbalanced differential resistive thermometer, taking R3 = R4 = const. Such circuits are used quite often.

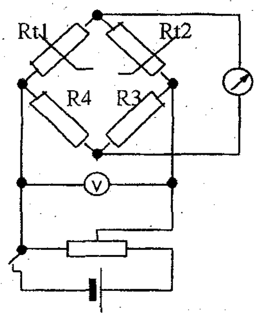

Fig.4.2

We'll see it.

8. THERMOELECTRICAL THERMOMETERS.

Thermoelectrical thermometers are based on laws of thermoelectricity. I'd like to introduce two of them for you.

1. Zeebek's law.

Let's take a circuit (see fig 4.3) Here A is a conductor made from one sort of metal, B - from another metal. So, 1 and 2 are the junctions. If there is a temperature difference between junctions, a current i goes through the circuit:

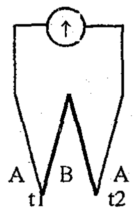

Fig.4.3. Thermocouple.

$$i = \frac{e \cdot (t_1 - t_2)}{R_\Sigma} \tag{4.4}$$

Here **e** is the specific thermoelectromotive force (thermoemf),
t1 and t2 are temperatures of junctions;
R_Σ is the whole resistance of the circuit.

Specific thermoemf "e" is a EMF, appearing when the temperature difference Δt is equal to one degree. Certainly, it depends on sort of metals A and B. For any metal A one can found it in special tables, when metal B is platinum.

2.Peltje's law.

Let's take another circuit (see fig.4.4.). Here the galvanometer is replaced by the battery. So a current given by the battery goes through circuit. In such a case there must be a temperature difference Δt, caused by the current.

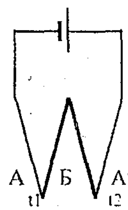

Fig. 4.4.

So we see - a temperature difference Δt causes a current (Zeebek's law). But the current (from a battery, for example) causes a temperature difference (Peltje's law).

Zeebek's law is particularly interesting for us, because it gives the opportunity to measure a temperature difference Δt. Really, having the circuit (fig.4.3.) one may determine the temperature difference Δt, measured the current by galvanometer! Such an apparatus is called *thermocouple*.

Pay attention - it's possible to measure only temperature difference, not temperature itself by the thermocouple!

But the value of specific thermoemf e is low (10^{-3} by the order) Thus, the current i is low too. To raise it let's use a circuit with many thermocouples (see fig.4.5).

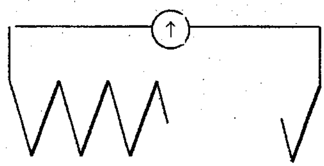

Fig.4.5.Thermopile.

It is called thermopile. The current through the galvanometer may be expressed by the formula:

$$i = \frac{ne(t_1 - t_2)}{nR_t + R_g + r}, \tag{4.5}$$

where n is a number of thermocouples.

R_g is the inner resistance of galvanometer,

r is the resistance of wires,

R_t is the resistance of thermocouples.

Now we can derive the expression for sensitivity of thermopile (S):

$$S = \frac{di}{d(t_1 - t_2)} = \frac{ne}{nR_t + R_g + r}. \tag{4.6}$$

But let's pay attention to the following important circumstance. If $nR_t >> R_g + r$ the expression for S can be rewritten as:

$$S = \frac{ne}{nR_t} = \frac{e}{R_t}.$$

Thus, S doesn't depend on n! Certainly, it isn't a favourable case. But when $nR_t << R_g + r$, the sensitivity is proportional to n:

$$S = \frac{ne}{R_g + r}$$

To sum up we may say it's useful to take low-resistance thermocouples for thermopile.

Now let's discuss the possible sources of errors for thermocouple and thermopile. We'll mention three possible errors.

1. The Peltje's effect. A current goes through thermocouple (or thermopile), and consequently, Peltje's effect occurs. Due to this the cold junction becomes warmer, and the hot junction colder.

2. Changing of wire resistant due to temperature changing.

3. Changing of galvanometer resistant.

To shoot all this errors the compensating circuit is used (see fig. 4.6).

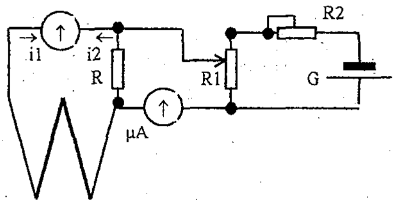

Fig.4.6. Compensating circuit.

The current from thermocouple goes through galvanometer. But there is another current i2 from the battery G, going towards it.

One may regulate i2 by the resistor R1. When i1 = i2 the galvanometer shows zero. Thus, the current through thermocouple becomes zero too. Peltje's effect doesn't occur, and the resistance of wire and galvanometer isn't important.

The value Δt can be measured upon the movable indicator of R1. Usually there are several resistors used instead of single one R1.

VOCABULARY

Definition – определение
Shoot – ликвидировать
Thermoelectrical thermometers – термоэлектрические термометры
Thermocouple – термопара
Junction – спай
Thermoemf – термоэдс, термоэлектродвижущая сила
Thermopile – термобатарея
Circumstance – обстоятельство
Favourable case – желательный случай
Compensating circuit – компенсационная схема

Lecture 5.

9. DEFORMATION THERMOMETERS

To begin with let's recall one of the main properties of materials. I mean the expansion of bodies under heating. Let solid rod have a length **l**. The dependence of **l** upon temperature t can be expressed by formula:

$$l = l_0(1+\beta \cdot t), \tag{5.1}$$

where l_0 is the length when $t = 0^0C$,
β is the expansion coefficient of the rod material.
It should be seemed possible to determine a temperature t by measuring the length **l**. But the thing is that the expansion coefficient β is too low – about 10^{-4} - 10^{-6} K^{-1} for solid materials. Thus the sensitivity of such method would be very low too.

A deformation thermometer consists of two plates concerted to each other. The materials of these plates are different. Such a construction is called *bimetallic plate.*

Being heated, bimetallic plate begins to bend. The angle of bend can be used as a measure of temperature. Let's derive the expression for the angle of bend as temperature function.

See fig.5.1. Here are two plates – upper and lower, they are made from different materials. Let's denote their expansion coefficients β_1 and β_2 respectively. The thickness of each of them is b, so the thickness of bimetallic plate at all is d=2b. The central angle is γ, the angle of bend is α. It can be easily shown that γ = 2α. R is the radius of curve up to the middle of the upper plate. So we can express the length of the upper and lower plates as:

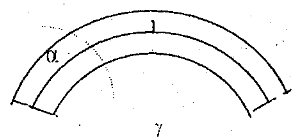

Fig.5.1. Bimetallic plate

$$l_1 = \gamma \cdot R, \tag{5.2}$$

$$l_2 = \gamma \cdot (R - \frac{d}{2}), \tag{5.3}$$

Let's subtract the equation (5.3) from (5.2). We obtain:

$$l_1 - l_2 = \gamma \cdot \frac{d}{2}. \qquad (5.4)$$

But from the other hand, according to the equation (5.1) this difference can be expressed as:

$$l_1 - l_2 = l_0 \cdot t(\beta_1 - \beta_2). \qquad (5.5)$$

Herefrom, taking into account that $\gamma = 2\alpha$, the following expression can be obtained:

$$\alpha = \frac{l_0 \cdot t \cdot (\beta_1 - \beta_2)}{d}. \qquad (5.6)$$

One can easily obtain the expression for the sensitivity:

$$S = \frac{d\alpha}{dt} = \frac{l_0(\beta_1 - \beta_2)}{d}. \qquad (5.7)$$

Thus, bimetallic plate has to be taken thin. Moreover, coefficients β_1 and β_2 have to be taken as different as possible and the length l has to be taken long.

This method is used in thermograph. I'd like you to read about thermographs yourself.

10. RADIATION THERMOMETERS.

Radiation thermometers give the opportunity to measure the temperature of bodies placed far away from an observer (e.g., to measure the ground temperature from an airplane).

The matter is that all bodies emit energy E_λ. This energy depends on the radiation wavelength λ and the temperature of the body. To analyze this dependence let's plot energy E_λ versus wavelength (fig.5.2).

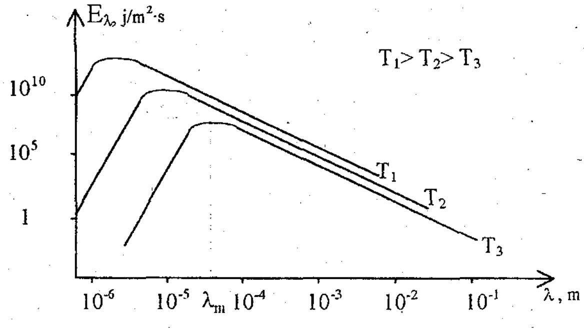

Fig. 5.2. The dependence of E_λ upon wavelength λ.

Considering this figure, we can come to three important conclusions.

1. The dependence of E_λ upon wavelength λ has an extremum. It moves to the left when T rises. It can be expressed by the formula:

$$\lambda_m \cdot T = C, \qquad (5.8)$$

Here λ_m is the wavelength, corresponding to maximum of E_λ. This is **Win's law.**

2. The integral energy E at whole spectrum rises when body is heated:

$$E = \int_0^\infty E_\lambda \cdot d\lambda = a\sigma \cdot T^4, \qquad (5.9)$$

where σ is Stephan-Boltsmann's coefficient, α is grey coefficient. It is **Stephan-Boltsmann's law.**

3. The value E_λ varies when temperature changes. This dependence is expressed by **Plank's law:**

$$E_\lambda = \frac{2\pi \cdot hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda \cdot kT}} - 1}. \qquad (5.10)$$

Here C is the light speed, h is Plank's constant.

Consequently, we can suggest three types of radiation thermometers. They are following.

1. Thermometer of maximal radiation. The output value is λ_m. This thermometer is based on Win's law.

2. Thermometer of integral radiation. The output value is E. It is based on Stephan-Boltsmann's law.
3. Selective radiation thermometer. The output value is E_λ, obtained in narrow wavelength range $\Delta\lambda$. For meteorological purposes $\Delta\lambda$ is selected in infrared range. The value E_λ is maximal in this range. That's why such thermometers are usually called *infrared thermometers.*

It can be shown that selective radiation thermometers (or infrared thermometers) are most sensitive.

Sensors of Radiation Thermometers

The main sensors of radiation thermometers are *photocell* and *photomultiplier.* Let's discuss them.

1. **Photocell.** The construction of this sensor is shown on fig. 5.3. Here one can see a vacuum glass balloon with two electrodes – anode (above) and cathode (below). As usual, anode is connected with a positive pole (here – through the resistor R) and anode – with a negative pole (here it is grounded). So there are a lot of electrons on cathode. But they can't leave it because of low energy. When cathode is irradiated by radiation

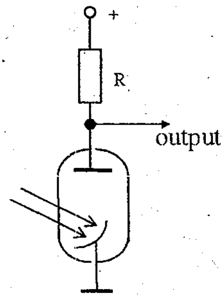

Fig. 5.3. Photocell.

flux the electron energy increases. They leave cathode and fly to anode. The potential of anode decreases. The higher is radiation, the deeper is the voltage step. So the voltage of anode can be the measure of radiation flux. After an amplifier it is measured by instrument.

2. **Photomultiplier.** It is similar with a photocell (see fig. 5.4). The only difference is that photomultiplier has some additional electrodes (one, two or more). The potentials of these electrodes are formed by voltage divider – here it is the chain $R_1 - R_2$. So the potential of additional electrode is higher than cathode's but more than

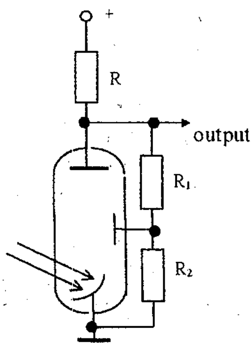

Fig.5.4. Photomultiplier.

anode's.

When an electron leaves cathode it flies to the first additional electrode and strikes other electrons from the surface. These electrons fly to the second electrode where each of them strikes another electrons, and so on. As a result, the whole avalanche of electrons flies to anode. Thus the sensitivity of photomultiplier is much more than of photocell.

Such sensors are used very often for light measurement. We'll meet them very soon.

VOCABULARY

Expansion – расширение
Rod – стержень
Bimetallic plate – биметаллическая пластинка
Bend – изгибаться.
Radiation thermometers – радиационные термометры
Emit – излучать
Wavelength – длина волны
Infrared – инфракрасный
Photocell – фотоэлемент
Photomultiplier – фотоумножитель
Electrode – электрод
Anode – анод
Cathode – катод
Electron – электрон
Voltage step – падение напряжения
Voltage divider – делитель напряжения
Strike from – выбивать (например, электроны)
Avalanche – лавина

Lecture 6.

Chapter 2

MEASUREMENTS OF ATMOSPHERIC HUMIDITY

Atmospheric humidity is one of the most important meteorological parameters. But before speaking about measurements of humidity let's list the values to describe the water contain in the air.

1. The *absolute humidity* **a** is the ratio of water vapor mass **m** to the volume **v** of air, containing this vapor:

$$a = \frac{m}{v} \tag{6.1}$$

2. The *partial water vapor pressure* **e**.
3. The *saturation water vapor pressure* E, that is the maximal partial water vapor pressure at a temperature.
4. The *relative humidity* **f**, that is the ratio of partial water vapor pressure to saturation water vapor pressure:

$$f = \frac{e}{E}. \tag{6.2}$$

5. The *dew point temperature* **t_d**, that is the temperature when the relative humidity becomes equal to 100% and dew appears.
6. The *mass fraction* is the mass of water vapor, containing in one kilogram of air.

All these values can be easily connected with each other. You may find formulas in any meteorology textbook.

Instruments used for measurements of humidity are called *hygrometers*. But one of them – a wet-and dry-bulb hygrometer is also known as *psychrometer*. Let's consider the theory of psychrometer.

1. PSYCHROMETER METHOD OF HUMIDITY MEASUREMENTS

Let's derive the equation, connected wet-bulb temperature **t'** with relative humidity **f**. First of all let's consider the process of evaporation from the wet-bulb. See fig. 6.1. Here **t** is an air temperature, **t'** is a wet-bulb temperature, Q_1 is. a heat stream from the wet-bulb due to evaporation, Q_2 is a heat stream to wet-bulb from air, Q_3 is a heat stream to wet-bulb from dry part of thermometer.

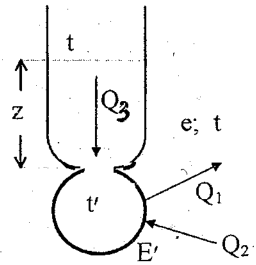

Fig.6.1.

Let f<1, thus t'<t. Suppose, the thermometer was watered at the moment $\tau=0$. The first appeared heat stream is Q_1. The temperature of thermometer began to fall. Then two other streams - Q_2 and Q_3 appeared. The higher is the temperature difference t- t', the more are Q_2 and Q_3. Soon the stable state will be achieved: $Q_2 + Q_3 = Q_1$. This is the base equation we begin our derivation from. Now let's express the streams Q_1, Q_2 and Q_3. To do so let's imagine the bulb as a big drop and use the Maxwell equation for the evaporation from a drop surface:

$$J = -4\pi \cdot R^2 \rho \cdot D \frac{dc}{dr} \quad (6.3)$$

Here J is the water vapor stream, R is the drop (or the bulb) radius, ρ is the density of air, D is the water vapor diffusion coefficient, C is the mass fraction of water vapor, r is the distance from the center of the bulb. Taking into account that the surface of bulb $S = 4\pi R^2$ and going from the mass fraction **c** to the partial water vapor pressure **e**, we get:

$$J = -\frac{0{,}622 \cdot S \cdot \rho \cdot D}{p} \cdot \frac{de}{dr} \quad (6.4)$$

The heat stream can be obtained by multiplying (6.4) by the specific heat of water evaporation L.

$$Q_1 = -\frac{0{,}622 \cdot L \cdot S \cdot \rho \cdot D}{p} \cdot \frac{de}{dr} \quad (6.5)$$

Here **p** is the atmospheric pressure.
The heat stream Q_2 can be written by following:

$$Q_2 = \lambda_1 \cdot S \cdot \frac{dt}{dr}, \quad (6.6)$$

where λ_1 is the coefficient of the heat conductivity of air. The heat stream Q_3 is expressed by the same formula:

$$Q_3 = \lambda_2 \cdot s \cdot \frac{dt}{dr}. \quad (6.7)$$

Here λ_2 is the coefficient of the heat conductivity of the material of thermometer – glass, for instance; s is the surface of the thermometer neck. Herefrom we get to the heat balance equation:

$$-\frac{0{,}622 \cdot L \cdot S \cdot \rho \cdot D}{p} \cdot \frac{de}{dr} = \lambda_1 \cdot S \cdot \frac{dt}{dr} + \lambda_2 \cdot s \cdot \frac{dt}{dr}. \quad (6.8)$$

Canceling dr let's integrate the left part from E' to e, and the right part from t' to t. We obtain:

$$\frac{0{,}622 \cdot L \cdot S \cdot \rho \cdot D}{p} \cdot (E' - e) = (\lambda_1 \cdot S + \lambda_2 s) \cdot (t - t'). \quad (6.9)$$

Herefrom we express the partial water vapor pressure e as a function of difference t- t':

$$e = E' - Ap(t - t'), \quad (6.10)$$

where A is so called *psychrometer coefficient*:

$$A = \frac{\lambda_1 \cdot S + \lambda_2 \cdot s}{0{,}622 \cdot L \cdot S \cdot \rho \cdot D}. \quad (6.11)$$

The formula (6.10) is called *psychrometer formula*. It allows to calculate partial water vapor pressure according to difference $\Delta t = t - t'$. But to use it we have to know the atmospheric pressure **p** and the psychrometer coefficient A. Let's take into account the dependence D upon p:

$$D_0 \cdot p_0 = D \cdot p,$$

where D_0 is the diffusion coefficient when the normal atmospheric pressure p_0. Then:

$$A = \frac{\lambda_1 + \lambda_2 \cdot \frac{S}{s}}{0{,}622 \cdot L \cdot \frac{\rho}{p} \cdot D_0 \cdot p_0}. \qquad (6.12)$$

We can see, in (6.12) all the values are constant (taking into account that $\frac{\rho}{p} = const.$). Only λ_1 and D_0 depend on wind speed V. These dependencies are similar:

$$\lambda_1 \propto \sqrt{V}; \qquad D_0 \propto \sqrt{V}.$$

So, when V increases the first term in the numerator of (6.12) increases too, and when it'll become much more than the second term $\left(\lambda_1 >> \lambda_2 \frac{S}{s}\right)$, the dependence of V in numerator and in denominator is cancelled. The psychrometer coefficient wouldn't depend upon wind speed. The psychrometer that answers this condition is called *ideal psychrometer*.

Really, the psychrometer coefficient depends on the wind speed:

$$A = A_\infty\left(1 + \frac{a}{V^b}\right), \qquad (6.13)$$

where **a** and **b** depend on the thermometer construction (in practice, $b \approx 0{,}5$).

How can the ideal psychrometer be done? Analyzing (6.12) we see – to do so we have to make the thermometer neck as thin as possible. Then the condition (6.13) would be achieved.

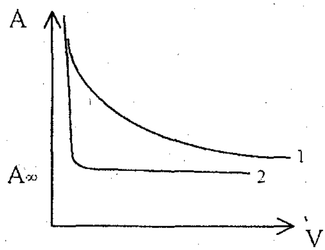

Fig.6.2. The dependence A(V): 1 – for real psychrometer, 2 – for psychrometer, similar to ideal.

For real thermometers TM-4 the psychrometer coefficient $A \approx 7{,}947 \cdot 10^{-4}\ K^{-1}$.

Pay attention – psychrometer tables, which we use to calculate the humidity, are contained for these thermometers only! If we take another thermometer, we can't use these tables, because the psychrometer coefficient is another!

Let's continue our derivation. Expressing the relative humidity from (6.2) and (6.11) we obtain:

$$f = \frac{E'}{E} - \frac{Ap}{E}(t - t'). \tag{6.14}$$

To express the ratio $\frac{E'}{E}$ we use the Clauseus-Klapeiron equation:

$$\frac{dE}{E} = \frac{L}{R_v} \cdot \frac{dT}{T^2}, \tag{6.15}$$

where R_v is the gaseous constant for water vapor. Integrating the left part (6.15) from E' to E, and the right part from T' to T we get:

$$ln\frac{E}{E'} = -\frac{L}{R_v}\left(\frac{1}{T} - \frac{1}{T'}\right). \tag{6.16}$$

Or:

$$ln\frac{E'}{E} = -\frac{L}{R_v}\frac{(T - T')}{T' \cdot T}. \tag{6.17}$$

Changing (T'-T) = t'-t and taking into account $T' \cdot T \approx T^2$, we obtain:

$$ln\frac{E'}{E} = -\frac{L}{R_v T^2}(t - t'). \tag{6.18}$$

Herefrom:

$$\frac{E'}{E} = e^{-\frac{L}{R_v T^2}(t-t')} \approx 1 - \frac{L}{R_v T^2}(t - t'). \tag{6.19}$$

The last expression is obtained by resolving the exponent into components and taking only two terms. Substituting (6.19) into (6.14) we obtain the final equation:

$$f = 1 - \left(\frac{L}{R_v T^2} + \frac{Ap}{E}\right) \cdot (t - t'). \tag{6.20}$$

Herefrom we obtain the expression for the sensitivity:

$$S = \frac{d(t-t')}{dt} = -\frac{1}{\frac{L}{R_v T^2} + \frac{Ap}{E}} \tag{6.21}$$

Let's analyze this expression. To begin with we see – the sensitivity is negative. It can be understood very easy – when the relative humidity rises, the psychrometer difference t-t' decreases. When humidity is 100% t = t'.

Secondary, the sensitivity depends on temperature. The dependence is plotted on fig.6.3.

When temperature is negative, the sensitivity is very low. That's why in winter, when the frost is strong, psychrometers aren't used.

Pay attention to the absolute value of sensitivity - it is about 0,1 K/%. It means, the high precision can't be achieved by psychrometers.

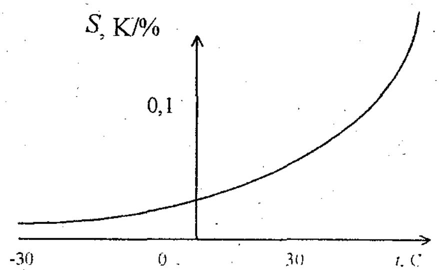

Fig.6.3. The dependence of psychrometer sensitivity on temperature.

In modern remote devices thermoresistors are used instead of mercury thermometers. The psychrometer coefficients are obtained experimentally. Psychrometer formula (6.10) is inputted into program of computer and the relative sensitivity is calculated and shown on indicator. Stations CRAMS-2 and CRAMS-4 operate by such a way.

VOCABULARY

Partial water vapor pressure – парциальное давление водяного пара
Saturation water vapor pressure – давление насыщения
Mass fraction –массовая доля
Stable state – установившееся состояние
Specific heat of water evaporation – удельная теплота парообразования
Cancel – сокращать
Psychrometer coefficient – психрометрический коэффициент

Lecture 7.

2. DEFORMATION HYGROMETER.

Some materials, for example, human hair free from oil and grease, can change geometrical sizes when relative humidity changes. The thing is that surface of hair contains small pores, filled by liquid water when humidity is high. For example, the dependence of hair length l upon relative humidity f may be expressed by formula:

$$l = l_0 k \cdot \ln f \qquad (7.1)$$

Here l_0 is the length of absolutely dry hair, k is a constant coefficient. Thus, the sensitivity of hair hygrometer S is:

$$S = \frac{dl}{df} = \frac{l_o \cdot k}{f} \qquad (7.2)$$

It's clear that the scale of hair hygrometer is non-linear.
Such method is used in hair hygrograph. I'd like you to read about it in a textbook.

Another material used for hygrometers is organic film. Usually it's used for airsounds, for sensors of stations and so on.

3. CONDENSATION HYGROMETER (DEW-POINT HYGROMETER)

As you known, when temperature is equal to dew point, the humidity is equal to 1. Thus, symbolising the saturation vapour pressure at dew-point temperature T_d by E_d, we can notice, that partial water vapour pressure e is equal to E_d:

$$e = E_d$$

And the relative humidity f at air temperature t:

$$f = \frac{e}{E} = \frac{E_d}{E}. \qquad (7.3)$$

Thus, if the dew-point temperature Td and air temperature T are known, the relative humidity f can be easily calculated. Let's derive the dependence of T_d on f. Integrating Clausius-Klapeiron equation from T_d to T (air temperature), we obtain:

$$\ln\frac{E}{E_d} = -\frac{L}{R_v}\left(\frac{1}{T}-\frac{1}{T_d}\right). \qquad (7.4)$$

Expressing T_d from this formula, we produce:

$$T_d = \frac{1}{\frac{1}{T}-\frac{R_v}{L}\ln f}. \qquad (7.5)$$

As usual, let's derive the expression for the sensitivity S of condensation hygrometer. According to definition of sensitivity:

$$S = \frac{dT_d}{df} = \frac{R_v}{L\cdot\left(\frac{1}{T}-\frac{R_v}{L}\ln f\right)^2\cdot f}. \qquad (7.6)$$

Analysing this expression, one may come to the following conclusions.

1.When relative humidity increases, the sensitivity diminishes.

2.When temperature T increases, the sensitivity increases too. These conclusions may be expressed graphically (see fig.7.1).

The dimension of S is degree by percent (the same as for psychrometer). But the absolute value of S is about 0.5 – 1 degree by percent. It's one order of magnitude more that the sensitivity of psychrometer!

Thus, a condensation hygrometer is the most sensitive instrument for humidity measurement. But the process of measurement is the most durable. Nothing to do, everything demands to be paid off!

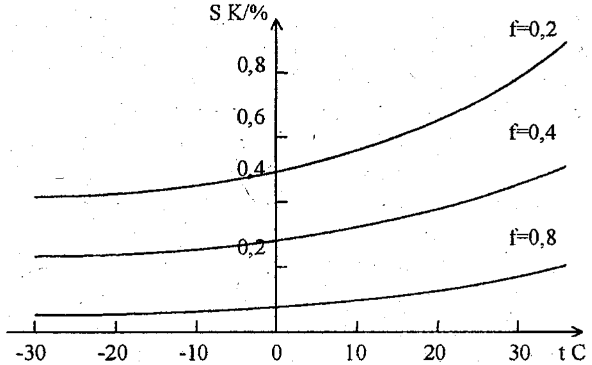

Fig.7.1. The sensitivity of hair hygrometer as a function of temperature t and humidity f.

This method can be used in winter as well as in summer. The problem is to construct the device that determines and measures the dew-point temperature. Let's consider such a device.(see fig. 7.2).

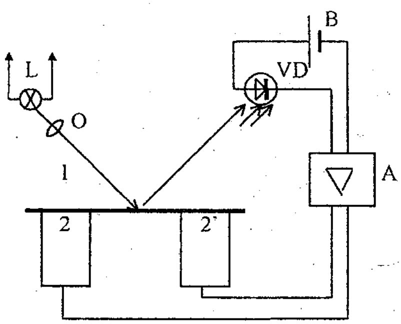

Fig.7.2. Condensation hygrometer.

Here (1) is a metal mirror, (2) and (2') are little semiconductor fridges. L is a source of light (usual lamp or a light-diode), VD is a photodiode, G is a source of current (e. q., a pile), A is an amplifier, "O" is an objective.

Light-diode emits the light-beam, focused by an objective "0". The light-beam, reflected by the mirror (1) goes to the photodiode VD. Being illuminated by light it is on.. A current from the source B goes through photodiode to the amplifier A and then to fridges. The mirror's temperature falls. When it becomes equal to dew point, a condensation on mirror's surface begins. The light-beam can't be reflected, it's scattered. Being not illuminated by light, the photodiode becomes off. The current doesn't go to fridges, the mirror's surface becomes heated by air. Soon it's temperature rises above dew point, the light-beam goes to photodiode, photodiode is on and the cycle repeats. Thus, the mirror's temperature is about T_d. It can be measured by resistive thermometer, for example.

Pay attention - this device is an example of feedback control system we have already spoken about! The current, going through photodiode, is a disbalance signal, the fridge is an executive element. Such systems are used very often.

VOCABULARY

Grease – жир
Durable – длительный
Semiconductor fridges – полупроводниковые холодильники
Light-diode – светодиод
Photodiode – фотодиод
Pile – батарейка
Objective – объектив
Photodiode is on – фотодиод открыт (is off – закрыт)

Lecture 8

4. ELECTROCHEMICAL HYGROMETER.

Electrochemical hygrometers are divided into two groups:
1. Electrolytic hygrometers.
2. Sorption hygrometers.

Let's consider electrolytic hygrometers.

Any salt (NaCl, for example), being solved in water, dissociates by ions. Of course, ions are charged – there are positive and negative ions in solution. On the other hand, water molecules are dipoles. Thus, molecules near ion (positive ion, for example) have to be oriented (see fig. 8.1). One may say, these molecules are connected with ion.

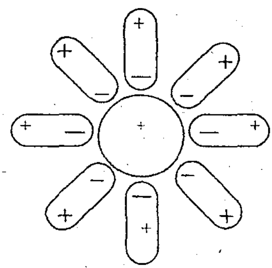

Fig.8.1 Hydrate envelope around ion in solution.

There may be the second and the third layer of molecules around the ion, and so on. But the connection of these layers with the ion is weaker. The ion becomes similar to frightened hedgehog.

Such an envelope around the ion is called *hydrate envelope*, and the ion itself is called *hydrate ion*.

Now, it's clear, the evaporation from such solution is difficult – most of water molecules are connected in hydrate envelopes. Thus, the saturation water vapour pressure E* above such solution is less than that above clear water. It's Rauhl's law, it can be expressed by the formula:

$$E^* = E(1 - ic\frac{\mu}{\mu^*}) \tag{8.1}$$

where E is the saturation vapour pressure over a clear water,

i is the Vant-Hoff's coefficient,

c is the concentration of solution,

μ and μ^* are molecular masses of water and the salt respectively.

Now, let's consider the processes of evaporation or condensation in wet air. If the solution is placed to wet air, and partial water vapour pressure $e > E^*$, the condensation takes place. Thus, the solution becomes diluted, and E^* increases. Soon it becomes equal to e:

$$E^* = e \tag{8.2}$$

The condensation stops.

When water vapour pressure $e < E^*$, the evaporation takes place. The solution becomes concentrated, c increases and E^* diminishes. When $E^* = e$ the evaporation stops.

Thus, we see - E^* is always equal to e (see formula 8.2), this is the only stable state for solution. Therefore E^* and c may serve a measure for a water vapour pressure and relative humidity f. The problem is to determine the concentration c.

One possible method to solve this problem is to measure the resistance of thin pored film, penetrated by solution. The resistance depends on concentration – when concentration increases, the resistance diminishes. Consequently, the dependence of the film resistance on relative humidity you can see on fig.8.2. As to measuring the resistance of solution – it's measured by bridge circuit we have already studied.

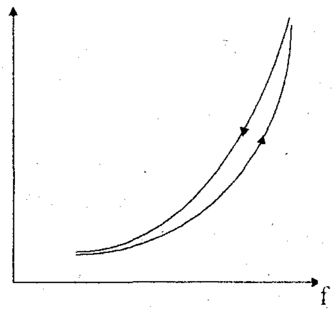

Fig.8.2. The dependence R on f.

The sources of errors. We shall discuss three sources of errors for electrolyte hygrometers.

1. Errors due to film hysteresis. Surface layer of film exchanges a water vapour with air rather quickly, but inner layers – not so quickly. Therefore inner layers may "remember" previous state. Due to this the instrument overreads when humidity falls, and underreads when humidity increases (see fig. 8.2). Such a property is named *hysteresis* of film. To diminish hysteresis thin films are used.

2. Errors due to change of temperature. The resistance of film depends on the air temperature. To diminish this error two bridge circuits are used (fig. 8.3).

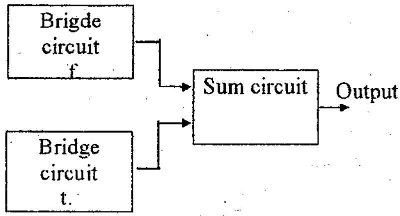

Fig. 8.3. Thermocompensation block-diagram.

The signal from measuring diagonal of the upper bridge circuit depends on humidity and temperature. The signal from lower bridge circuit depends upon temperature only. The sum circuit sums these signals. So, if the temperature changes, both signals change and the lower signal compensate the upper. If the humidity changes, the upper signal changes, but the lower doesn't! Such a circuit gives the output signal that doesn't depend on temperature.

3. The expansion of the solution by direct current (d.c). To avoid it the alternating current (a.c.) is used. The output signal is rectified.

5. SORPTIONAL HYGROMETERS

They are very similar to electrolytic hygrometers. The difference is that the film of sorption hygrometers contains the dry solt, not solution. Being placed to wet air, this solt transforms to saturation solution. But there is the mixture of salts within the film, and every salt becomes solution at certain humidity. Thus, the solution within the film is always saturated. The mass of solution depends on humidity.

To measure the mass of solution two methods can be used.

The first method is the measurement of the film resistance. But the resistance R decreases when the mass of the solution increases. Therefore, the dependence R(f) isn't the same, as for electrolytic hygrometers (compare fig. 8.4 with the fig.8.2).

When air is absolutely dry (f = 0), there is no water within the film. But dry solt doesn't conduct the current, so the resistance of film tends to infinity.

Such a method is realised by the device AGS-210. The sources of errors for it are the same, as for electrolytic hygrometers. The methods to avoid them are the same too.

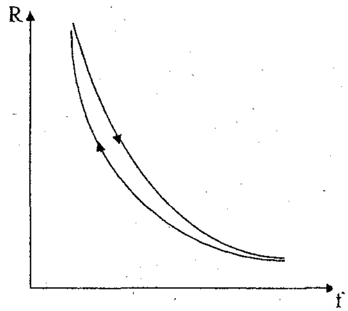

Fig.8.4. The dependence R(f) for sorption hygrometer.

The second method is to measure the mass of water within the film. To do so the film is placed on the surface of quartz. As you know, quartz is piezoelectric. Thus, being used as the initial element of the electric generator, it oscillates. The sinusoidal signal appears. The matter is that the frequency of this signal depends on the mass of the quartz (and the mass of film, of course!). We see, the frequency of this signal depends on humidity.

To measure the frequency of the electric current we have to use the *frequency meter*. This method is realised in hygrometer "Volna" and "Volna-2" produced by our plants some years ago.

VOCABULARY

Dissociate – диссоциировать
Hydrate envelope – гидратная оболочка
Hysteresis – гистерезис
Piezoelectric – пьезоэлектрик
Frequency meter – частотомер

Lecture 9.

6. RADIATION HYGROMETER

Speaking about radiation, I'd like to resemble you that any gas has absorption bands. These are zones of spectrum in which radiation is absorbed by molecules of gas. The absorption bands are lied within different zones of spectrum for different gases. For example, for water vapour there are two main absorption bands – from 250 to 300 nanometers and at the wavelength 694,383 nm. It follows that the radiation within absorption band, going through air, depends on amount of water vapour, i.e. on humidity. This process can be described by Bouguer-Lambert's law:

$$J = J_0 \cdot e^{-k_\lambda l \cdot a}; \qquad (9.1)$$

Here J is the radiation, received by a receiver,

J_0 is the radiation, transmitted by a transmitter,

k_λ is the index of absorption: it depends on a wavelength

l is a distance from transmitter to receiver,

a is the absolute humidity.

Consequently, it's feasible to measure the absolute humidity by this way. The index of absorption for water vapour is known, it's about 0.45 sm^2/g (centimetre squared per gram) for λ = 694,383 nm.

Well, let's derive the expression for sensitivity of this method. The input value is a, the output value is J, and thus the sensitivity is:

$$S = \frac{dJ}{da} = -k_\lambda \cdot l \cdot e^{-k_\lambda l \cdot a}; \qquad (9.2)$$

The dependence of sensitivity S on a distance l is an external function. S is equal to zero when l = 0, and it tends to zero when l tends to infinity:

$$S|_{l=0} = 0; \qquad S|_{l \to \infty} = 0;$$

Let's examine the function S(l)on maximum. To do so one has to take a derivative:

$$\frac{dS}{dl} = -k_\lambda \cdot e^{-k_\lambda l \cdot a}(1 - k_\lambda \cdot l \cdot a). \qquad (9.3)$$

The equation (9.3) has two solutions:

1) $e^{-k_\lambda l \cdot a} = 0$, so $l \to \infty$.

2) $l = \dfrac{1}{k_\lambda \cdot a}$.

The first solution isn't interesting for us (S = 0), but the second corresponds to maximum S(l). Therefore, the distance between transmitter and receiver must be determined according to this demand.

Now let's discuss the sources of errors of radiation hygrometer. There are three of them.

1) The influence of carbon dioxide CO_2, having the absorption band near water vapour. To avoid this difficulty a carbon dioxide chamber is placed on the way of radiation. The part of radiation absorbed by carbon dioxide would be absorbed within this chamber. Therefore, the influence of the atmosphere's carbon dioxide is negligible.

2) Spurious signal – day light and others. To avoid this error, the signal, we deal with, must be modulated. It means that the radiation must be interrupted with a known frequency. Of course, the spurious signal isn't modulated. The modulator construction has been already shown, when we discussed the radiation thermometers.

3) The absorption of radiation by aerosols, not by water vapour only. But the thing is that aerosols absorption doesn't depend on the wavelength. It's nonselective absorption. Thus, one may use two transmitters with different wavelengths λ_1 and λ_2. λ_1 is selected within the water vapour absorption band, λ_2 is outside it. The ratio $\dfrac{J_1}{J_2}$ doesn't depend on the aerosols absorption because aerosols absorb both J_1 and J_2. But water vapour absorbs only J_1. Thus, the ratio $\dfrac{J_1}{J_2}$ depends on the water vapour amount only.

The desirable property of this hygrometer is the absence of inertia.

7. RADIATION-ACOUSTIC HYGROMETER

This hygrometer is based on Bell-Tyndall's phenomenon. Let a volume of wet air be in a closed chamber. Absorbing the radiation within absorption band of water vapour, the air is heated. The pressure in the chamber increases. This increasing depends on the water vapour amount. If the radiation is interrupted with an acoustic frequency, the pressure oscillates with the same frequency. The air would sound. It's easy to understand that sound amplitude depends on humidity. The sound is transformed to electric signal by microphone.

This method has the same sources of errors, as the radiation hygrometer, we have just spoken about. They are avoided by the same methods.

8. CAPACITOR HYGROMETER.

As well known, the capacity of capacitor C is expressed by formula:

$$C = \frac{\varepsilon \cdot \varepsilon_0 \cdot s}{4\pi \cdot d}, \qquad (9.4)$$

Here ε is dielectric constant of the substance between plates of capacitor,

S is a space of plates,

d is the distance between the plates,

ε_0 is the constant coefficient, the dielectric constant of vacuum.

Let the substance between plates be wet air. Thus ε is the dielectric constant of air. But it depends on humidity:

$$\varepsilon = 1 + \frac{a}{T}(p + b\frac{E}{T} \cdot f), \qquad (9.5)$$

Here b and a are constant values,

T is the air temperature, expressed in Kelvin,

p is the atmospheric pressure,

E is the saturation vapour pressure,

f is the relative humidity.

Substituting ε to the formula for C, we get:

$$C = \frac{\varepsilon_0 \cdot s}{4\pi \cdot d}\left(1 + \frac{a}{T}\left(p + b\frac{E}{T} \cdot f\right)\right). \qquad (9.6)$$

It allows us to offer the method for humidity measurement. Measuring the capacity of air capacitor we can determine relative humidity. Of course, we have to measure the temperature T and to determine the saturation water vapour pressure E. But this method is attractive because of the absence of inertia. It's used to measure fluctuations of humidity.

Let's express the sensitivity of this method. According to sensitivity definition:

$$S = \frac{dC}{dT} = \frac{\varepsilon_0 \cdot s}{4\pi \cdot d} \cdot ab\frac{E}{T^2}. \qquad (9.7)$$

This expression can be represented graphically (see fig. 9.1).

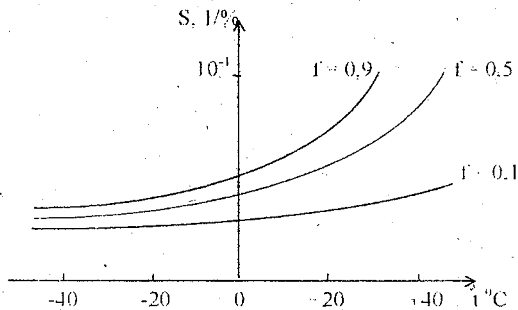

Fig. 9.1.

The dependence E on T is stronger than T^2. Thus the sensitivity increases with T rising.

For measuring the capacity C different circuits are used. For example, one may use an oscillatory circuit involving air capacitor. Resonance frequency of such a contour depends on a capacity C. The generator involving this contour generates a sinusoidal signal. The frequency of this signal depends on C, and on humidity consequently.

This method is realised in hygrometers, produced by Finnish firm "Vaisala".

VOCABULARY

Absorption bands – полосы поглощения
Index of absorption – показатель поглощения
Spurious signal – паразитный согнал
Modulated – модулированный
Nonselective – неселективный
Capacitor – конденсатор
Oscillatory circuit – колебательный контур

Lecture 10.

MEASUREMENT OF WIND.

Wind velocity is a parameter that can't be measured directly. Thus transducers for converting wind velocity into another magnitude - angular velocity, for example, are used. Such transducers are called rotation anemometers (or *rotoanemometers*). Two main types of rotoanemometers are known:

1. Anemometer with cups.
2. Anemometer with propeller.

Speaking about the construction of transducer we'll use another classification. Now let's consider the theory of rotoanemometers with cups.

THE THEORY OF CUP ROTOANEMOMETERS.

The cup rotoanemometer consider of four (may be three) cups mounted symmetrically at right angles to a vertical axis (fig. 10.1).

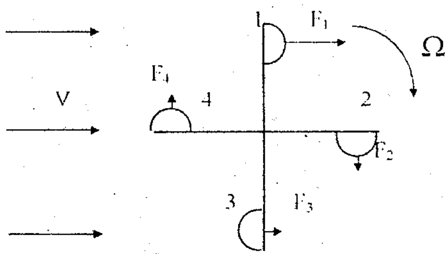

Fig. 10.1. The rotating part of cup rotoanemeter.

The force F_1 exerted by the wind is greater on the inside surface than F_3 on the outside and so cups rotate.

But when they rotate, the force F_3 increases (the cup moves upwind) and F_1 decreases (the cup moves downwind). When $F_1 = F_3$ it is stable state and the angular velocity of rotation is constant.

To begin with let's consider the stable state only. To express the formula of anemometer sensitivity the angular speed V must be represented. According to theory of aerodynamics the wind pressure to the cup 1 (see fig. 10.1) is:

$$p_1 = \frac{1}{2} \cdot C_1 \cdot \rho \cdot S \cdot (V')^2. \qquad (10.1)$$

Here C_1 is the aerodynamic resistance coefficient for the cup (1);

S is the projection of cup surface area to plate that is perpendicular to wind direction;

ρ is the air density ;

V' is the linear speed of cup in relation to moving air.

And the wind pressure to the cup 3 is:

$$p_3 = \frac{1}{2} \cdot C_3 \cdot \rho \cdot S \cdot (V')^2. \qquad (10.2)$$

Let's assume:

1. The friction is negligible.
2. The sum of all forces doesn't depend on position of cups, it is constant. It allows us to consider the position drawn in fig. 10.1 only.
3. The forces to cups (2) and (4) are negligible, being composed with those to cups (1) and (3).

Thus the equation for stable state may be written as follows:

$$R \cdot p_1 - R \cdot p_3 = 0, \qquad (10.3)$$

or, substituting (10.1) and (10.2):

$$\frac{1}{2} C_1 \cdot \rho \cdot S \cdot (V - U)^2 = \frac{1}{2} \cdot C_3 \cdot \rho \cdot S \cdot (V + U)^2, \qquad (10.4)$$

where R is the radius of the anemometer's arm.

U is the linear speed of cup.

As is known:

$$U = \Omega \cdot R.$$

Where Ω is the cup's angular velocity.

Herefrom we obtain:

$$\frac{C_1}{C_3} (\frac{V}{U} - 1)^2 = (\frac{V}{U} + 1)^2. \qquad (10.5)$$

Let's denote:

$$\frac{V}{U} = \sigma .$$

Solving this equation for σ, we obtain:

$$\sigma = \frac{\frac{C_1}{C_3}+1}{\frac{C_1}{C_3}-1} \pm \sqrt{\left(\frac{\frac{C_1}{C_3}+1}{\frac{C_1}{C_3}-1}\right)^2 - 1}$$

The ratio $\frac{C_1}{C_3}$ doesn't depend upon form of cup. It's approximately constant. It may be assumed that $\frac{C_1}{C_3} = 4$.

Thus the equation for σ has two roots:

$$\sigma_1 = 3;\ \sigma_2 = \frac{1}{3}.$$

It is evident, σ_2 is the false solution, because V > U, thus $\sigma > 1$. Taking it into account, we can write:

$$\Omega = \frac{V}{\sigma \cdot R}, \qquad (10.6)$$

where $\sigma = 3$.
Then let's express the sensitivity of rotoanemometer:

$$S = \frac{d\Omega}{dV} = \frac{1}{\sigma \cdot R}. \qquad (10.7)$$

Consequently, to increase the sensitivity, we have to use rotoanemometers with small R. The dependence of Ω upon V can be plotted (see fig. 10.2).

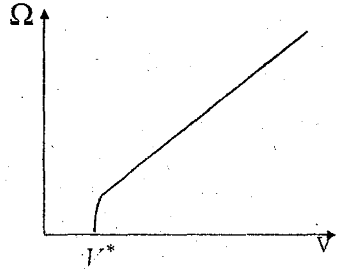

Fig. 10.2. The dependence of angular speed Ω upon V. V^* is the threshold speed.

The value V^* is called *threshold wind speed* for the anemometer. It is due to friction. We assumed the friction is negligible, but it isn't so when the wind speed is low.

Of course, it's desirable to take an anemometer with low V^*. The way to do it is to make the friction as low as possible.

But this is only a half of the problem. Now let's consider nonstable state - when anemometer rotates with acceleration or deceleration. One can simply understand this situation - the wind speed is changing by step. So let's assume:

1. The wind speed is changing from V_0 to V_e thus angular speed of anemometer changes from ω_0 to Ω.
2. The friction is negligible.
3. The sum of all moments of forces for anemometer can be represented by formula:

$$\sum_i M_i = kV^2 \cdot \frac{\Omega - \omega}{\Omega}. \qquad (10.8)$$

Here **k** is a coefficient (it is constant for the anemometer),

ω is the angular speed,

n is the number of cups.

On the other hand the movement equation for rotating system can be written:

$$K \cdot \frac{d\omega}{d\tau} = \sum_i M_i = kV^2 \frac{\Omega - \omega}{\Omega} . \quad (10.9)$$

Here K is a moment of inertia of the whole system;
τ is the time .
Separating the variables, we obtain:

$$\frac{d\omega}{\omega - \Omega} = -\frac{k \cdot V^2}{K \cdot \Omega} d\tau$$

Let's integrate the right part from 0 to τ and the left part from ω_0 to ω consequently:

$$\ln \frac{\omega - \Omega}{\omega_0 - \Omega} = -\frac{k \cdot V^2}{K \cdot \Omega} \cdot \tau .$$

Or:

$$\omega - \Omega = (\omega_0 - \Omega) \cdot e^{-\frac{kV^2}{K\Omega} \cdot \tau} . \quad (10.10)$$

Let's denote:

$$\frac{K \cdot \Omega}{k \cdot V} \equiv L . \quad (10.11)$$

Taking it into account we get the final equation:

$$\omega - \Omega = (\omega_0 - \Omega) \cdot e^{-\frac{V \cdot \tau}{L}} . \quad (10.12)$$

The dimension of L is length. When $V \cdot \tau = L$, the equation takes the form :

$$\omega - \Omega = \frac{\omega_0 - \Omega}{e} . \quad (10.13)$$

The time τ^* satisfying this equation is called the *time of synchronisation*. So, let's write the definition:

The time of synchronisation is the time, during which the angular speed difference between anemometer angular speed and stable angular speed would be decreased by **e** times.

On the other hand, the air stream way during the time is called the *constant distance* L.

Let's transform the expression in L:

$$L = \frac{K \cdot \Omega}{k \cdot V} = \frac{K}{k \cdot R \cdot \sigma}. \qquad (10.14)$$

Or, taking into account $K = n \cdot mR^2$, where **m** is the mass of one cup, we can get:

$$L = \frac{n \cdot m \cdot R}{k \cdot \sigma}. \qquad (10.15)$$

From this expression we can see that the constant distance L is a constant for the anemometer indeed. On the contrary, the time of synchronisation isn't constant, it depends upon wind speed:

$$\tau^* = \frac{L}{V} \qquad (10.16)$$

Herefrom the surprising conclusion can be got! When the wind speed is high (and consequently, Ω is high too), the anemometer perceives it more quickly ! (See fig. 10.3).

Now let's take into account the possible fluctuations of wind speed. The anemometer would quickly respond to high speed, and rather slowly - to low speed. When we measure an average wind speed, we obtain the result that is below the true value.

So, rotoanemometer underreads the average wind speed. This conclusion is very important. Rotoanemometers aren't suitable to measure quick fluctuations of wind speed.

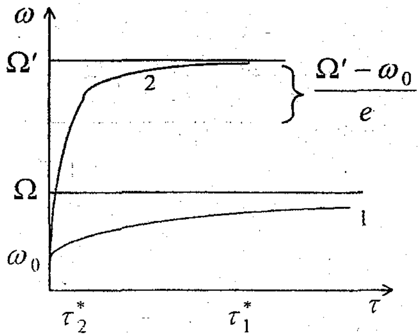

Fig.10.3. The dependence of ω on τ when the wind speed is low (1) and when the wind speed is high (2).

Of course, the possible error may be diminished if the constant distance is low. Analysing the expression for L, we see - the anemometer must be quite compact (with small R) and light (with little **m**).

VOCABULARY

Transducer – датчик (блок элементов)
Mount – устанавливать, монтировать
Exert – оказывать давление, вызывать
Upwind – против ветра
Downwind – по ветру
Stable state – установившееся состояние
False solution – постороннее решение
Threshold – порог, threshold speed - пороговая скорость
Nonstable – неустановившийся
By step – скачком
Time of synchronisation – время синхронизации
Constant distance – путь синхронизации
Perceive – воспринимать

Lecture 11.

Now let's discuss the classification of anemometers according to construction of transducers. We'll study four types of rotoanemometers. They are:

1. Hand anemometer.
2. Inductive anemometer.
3. Contact anemometer.
4. Photoelectric anemometer.

Hand anemometer is one of the instruments used very often. This is a portable anemometer based on the principle of the windmill. When cups (or propeller) rotate, the pointer is moving clockwise on a dial. The number of divisions passed by the pointer during a measured time interval is determined. It is proportional to the wind speed. The average speed can be read from a special graph.

This anemometer is a simplest one. But it isn't a remote instrument. It can't be used in modern measurement systems.

INDUCTIVE ANEMOMETER

This is a remote instrument. The sensor of inductive anemometer is shown on fig. 11.1.

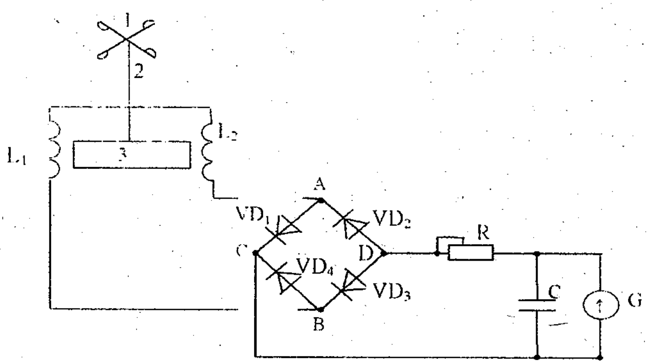

Fig. 11.1. Inductive anemometer with current generator.

Here (1) are the cups, (2) is an axis, (3) is the magnet rotated by cups, L_1 and L_2 are coils, connected in series. When magnet rotates, an electromotive force (EMF) is inducted in the coils. So, it is the electric current generator. Of course, it is a.c., not d.c. Its frequency and amplitude depends on the wind speed. To measure the amplitude of the current it must be rectified. The diode bridge $VD_1 \dots VD_4$ is used here for it. When point (A) has a positive half-cycle of current signal (and B has a negative one) the diodes VD_1 and VD_3 are on, but VD_2 and VD_4 are off. On the contrary, when (A) has a negative half-cycle (and B has a positive one) the diodes VD_2 and VD_4 are on, but VD_1 and VD_3 are off. Thus, point (C) has a pulsing voltage signal (see fig. 11.2, curve (1)).

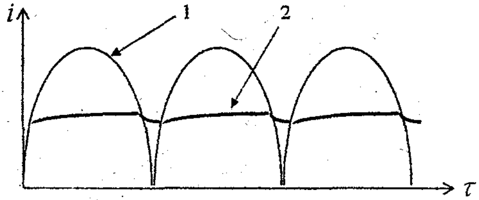

Fig. 11.2.

To smooth out the pulsing voltage there is the RC-filter in the circuit. The capacitor C charges when voltage is high, and discharges when it is low. But it is quite a slow process if the product RC is high. So, using a capacitor with a high capacity we'll obtain the output signal being almost constant. It can be measured by galvanometer G. Of course, its scale is calibrated in meters per second to measure wind speed

The sources of errors. The inductive anemometer has two main sources of errors.

1. The error due to magnet ageing. The thing is that magnet magnetisation decreases in time. Thus output current signal decreases too. To eliminate this error the anemometer is to be verified from time to time. The output current can be varied with a variable resistance R. So the calibration may be restored.

2. The temperature error. The sensor of anemometer is placed outdoors. Thus the coils have a temperature of air. The resistance of coils R depends on temperature. But according to Ohm's law the output current **i** depends on resistance:

$$r_\Sigma = R_k + R_{kb} + R + R_i \approx R + R_i, \qquad (11.1)$$

where R_k is the resistance of coils.
R_{kb} is the resistance of cable,
Ri is the inner resistance of galvanometer.

But if the resistance R is much greater than $R_k + R_{kb}$ the expression on **i** can be written:

$$i = \frac{U}{R + R_i}.$$

Thus the temperature error can be eliminated.

The inductive anemometer is used rather often for remote measurements. For example, the remote meteorological station M - 49 has this anemometer.

CONTACT ANEMOMETER.

The idea of this anemometer is very simple. Once a revolution (or once an **n** revolutions) of rotoanemometer a special element closes an electrical contact. The current pulse appears. Thus the frequency of pulses is proportional to wind speed.

As you can see, this method has a frequency modulation of output signal. Such a signal is more tolerant to disturbances, than amplitude modulated one.

Various elements can be used to provide such a pulse generation. But most of modern instruments use *hermetic contact* (hercon) and a magnet (see fig. 11.3).

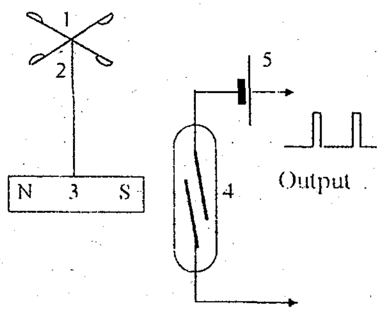

Fig. 11.3. Pulse anemometer with hercon.

Here (1) are cups, (2) is an axis, (3) is a magnet, (4) is a hercon. (5) is a source of current (battery, for example). The most interesting part of this construction is the hercon. It is a closed glass tube. There is a vacuum inside it. Two iron contacts are placed into this tube. Usually they are off. But when a pole of magnet is near hercon, the magnet attracts them and hercon is on. A current pulse goes to output. Thus the output signal has a form, pictured in the right part of fig. 11.3.

The problem of measuring the frequency of this signal can be solved by frequency meter or by counter.

Such a method is realised in meteorological station CRAMS - 2 we'll study next semester.

PHOTOELECTRIC ANEMOMETER.

Photoelectric anemometer also has a frequency-modulated signal. This is the advantage of this instrument. Its construstion is represented in fig. 11.4.

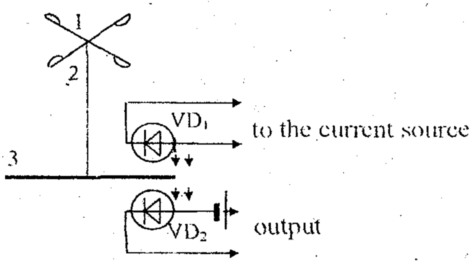

Fig. 11.4. Photoelectric anemometer.

Here (1) are cups. (2) is ah axis. (3) is the disk with perforations, VD_1 is light-diode, VD_2 is photodiode. Being placed into wind stream cups rotate. The disk (3) rotates too. When the light-diode is on, the photodiode can be irradiated by light beam. But the light can come to photodiode through the perforations only. Thus rotating disk interrupts the light. The frequency of light signal depends upon wind speed. But let's recall that photodiode is on only being irradiated by light. To sum up, we see - the output current signal represents pulses, such as can be seen in fig. 11.3. The frequency of this signal is higher than that of contact anemometer. This anemometer is used to measure the wind bursts. It has quite high sensitivity.

VOCABULARY

Windmill – ветряная мельница
Clockwise – по часовой стрелке
Dial – циферблат
Coil – катушка
In series – последовательно
Electromotive force (EMF) – электродвижущая сила (ЭДС)
Induct – индуцируется
a.c. – переменный ток
d.c. – постоянный ток

To be rectified – быть выпрямленным (о токе, напряжении)
Half-cycle – полупериод
To smooth out – сгладить
Ageing – старение
Magnetisation – намагниченнность
Eliminate – устранять
Restore – восстанавливать
Disturbances – помехи
Hermetic contact (hercon) – герметический контакт (геркон)
Advantage – преимущество
Frequency meter – частотомер, прибор для измерения частоты

Lecture 12.

LASER ANEMOMETER.

Laser anemometer is based on Doppler effect. I'd like to remind the essence of this effect to you. When periodic signal is perceived by a moving body, the frequency of this signal changes. If the body approaches to a transmitter, the frequency increases, if it moves away from the transmitter, the frequency decreases. We can introduce the frequency of perceived signal (ν') as a function of the body's velocity V:

$$\nu' = \frac{C+V}{\lambda} \tag{12.1}$$

Here C is the speed of signal's propagation,

λ is the wavelength of the signal.

If this signal is reflected by moving body and the observer perceives it, the frequency of perceived signal ν can be introduced as follows:

$$\nu = \frac{C+2V}{\lambda} \tag{12.2}$$

Suppose, we have a light signal. The wavelength of our light signal is constant. For this purpose we may use laser. The moving body is aerosol. There are many aerosols in the atmosphere, the speed of their motion is equal to the wind speed. Can we measure the wind speed, using this effect? It would be very difficult, because the light speed C is much more than wind speed V, and the variations of signal frequency is negligible.

Nevertheless, this method can be used to measure a wind speed. Let's use a *differential method* of measurement. An optical block-diagram of such a method is shown on figure 12.1. Here (1) is laser, (2) is semitransparent plate, (3) is a mirror, V is the velocity of aerosol (wind speed). Aerosol moves at the right angle to a bisectrix of crossing two light beams. V' and V" are projections of V to directions of light beam.

So, the aerosol reflects two signals. But frequencies of these reflected signals are different. The projection V" is directed *towards* the beam of light B, but V' has *the same* direction as the light beam A.

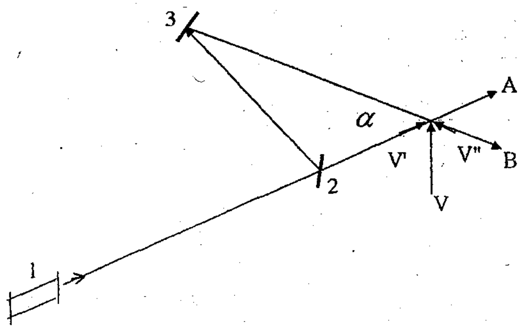

Fig. 12.1: Optical block-diagram of laser anemometer.

Thus frequencies of signals can be introduced by formulas:

$$\nu_1 = \frac{C - 2V \cdot \sin\frac{\alpha}{2}}{\lambda} \tag{12.3}$$

$$\nu_2 = \frac{C + 2V \cdot \sin\frac{\alpha}{2}}{\lambda} \tag{12.4}$$

But when the observer perceives two beams of light with different frequencies, the result signal is the sum of amplitudes. As a consequence of this process, the amplitude of result signal changes periodically, the frequency of this changing is the difference $\Delta\nu = \nu_2 - \nu_1$. Such an effect is called *beating*. Let's express the value of beating frequency.

$$\Delta\nu = \frac{4V \cdot \sin\frac{\alpha}{2}}{\lambda} \tag{12.5}$$

This is the frequency of changing amplitude of light, perceived by observer. Certainly, one can measure it. With a frequency meter, for example. Now we can calculate the wind speed V, if we know the angle α.

The sensitivity of laser anemometer can be expressed as follows:

$$S = \frac{d\Delta v}{dV} = \frac{4\sin\frac{\alpha}{2}}{\lambda} \tag{12.6}$$

This method is attractive due to the absence of inertia. Thus it can be applied to measure the fluctuations of wind speed. It can be used for measurements of wind speed at the distance 10 – 20 m. or more.

THE WIND DIRECTION MEASUREMENTS.

The wind direction is measured by a vane. You can see a vane in fig.12.2.

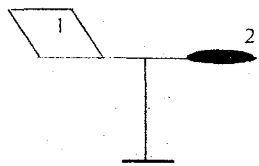

Fig.12.2. Vane.

Here (1) is a board. (2) is a counterweight. A wind rotates the vane and counterweight shows wind direction. This apparatus is very simple, but the difficulty is to make a remote device. Various methods can be used to do so. We'll consider only one of them: a synchro's method of information transmitting.

Synchro is an element, which allows us to transmit the information about an angle of rotating (e.g. rotating of vane).

It contains two blocks - synchro-transmitter and synchro-receiver. They are absolutely the same. Synchro-transmitter and synchro-receiver are connected with each other by cable. Each of them contains rotor and stator. Rotor is the rotating part, stator is unmoving. Rotor rotates within the stator (see fig. 12.3.). Rotor (see fig.12.3 A) is made of the iron, a coil (L_0) is reeled up to a piece of iron.

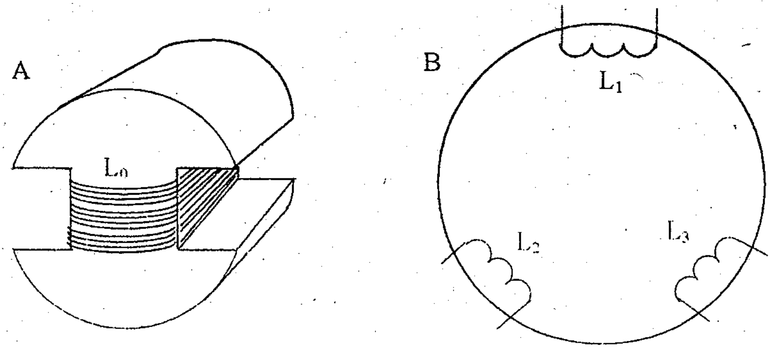

Fig. 12.3. Rotor of synchro (A) with a coil L_0, and stator (B) with coils L_1, L_2 and L_3.

Stator has three coils (L_1, L_2 and L_3), positioned at the angle 120° to each other (see fig. 12.3 B)

The coils L_1, L_2 and L_3 are absolutely the same. Both synchro-transmitter (ST) and synchro-receiver (SR) have the same construction. ST is placed near the vane, and the axis of the vane is connected with the rotor of ST. As to SR, it's placed within a room on the observer's desk and the rotor of SR is connected with lightweight scale pointer.

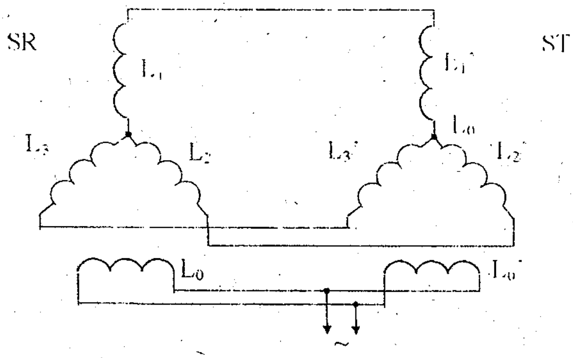

Fig. 12.4. Electric circuit of synchro-transmitter (ST) and synchro-receiver (SR).

When the vane is rotated by the wind, the rotor of synchro-receiver rotates to the same angle! How can it be done? To understand it let's review the circuit of ST and SR, pictured on fig. 12.4.

The coils L_1, L_2 and L_3 of synchro-transmitter are connected to the same coil L_1', L_2' and L_3' of synchro-receiver. The same about L_0 and L_0'. An alternating current feeds L_0 and L_0'. But this is a transformer connection of L_0 and L_1 (L_0 and L_2; L_0 and L_3), and, consequently, of L_0' and L_1' (L_0 and L_2'; L_0 and L_2'). Thus, there are voltages in L_1, L_2, L_3 and L_1', L_2' and L_3'. Let's denote this voltages (alternating!) as $U_{\sim 1}$; $U_{\sim 2}$; $U_{\sim 3}$ and $U'_{\sim 1}$; $U'_{\sim 2}$ and $U'_{\sim 3}$. You understand, these voltages depends upon angle of L_0 and L_1; L_0 and L_2; L_0 and L_3 and consequently, L_0' and L_1'; L_0' and L_2'; L_0' and L_3'. Suppose rotors of ST and SR have the same position. Then $U_{\sim 1} = U'_{\sim 1}$; $U_{\sim 2} = U'_{\sim 2}$; $U_{\sim 3} = U'_{\sim 3}$. Such a position of rotors is recalled *matching position*. The angle of L_0 and L_1 is equal to the angle of L_0' and L_1', the same about L_2 and L_3 can be said. At the matching position there are no currents in wires between stators ST and SR because of equal voltages. But when wind direction changes, the rotor of ST rotates and the position is not matching. Now $U_{\sim 1} \neq U'_{\sim 1}$; $U_{\sim 2} \neq U'_{\sim 2}$; $U_{\sim 3} \neq U'_{\sim 3}$. The currents go through the wires and through the coils of stators. These currents cause magnetic fields around coils to appear. These fields interacts with magnetic field around L_0 and L_0', rotating rotors. But there is only one rotor, that can be rotated - the rotor of synchro-receiver! Thus, it rotates and creates a new matching position. The scale pointer shows the direction of wind.

Another construction of synchro contains all the coils (L_0, L_1, L_2 and L_3) in stator. The rotor of such a synchro is a piece of iron having special form. There isn't a coil in such a stator. This construction is more convenient, it is called *contactless synchro*. Here rotor is only a core of transformer. It can rotate. The voltages in L_1, L_2 and L_3 depend on position of rotor. As to others, the action of contactless synchro is the same we have already discussed.

VOCABULARY

Propagation – распространение
Semitransparent plate – полупрозрачная пластина
Beating – биения
Vane – флюгарка
Counterweight – противовес
Synchro – сельсин

Rotor – ротор
Stator – статор
Reel up – наматывать
Matching position – согласованное состояние
Interact – взаимодействовать
Contactless – бесконтактный

Lecture 13.

ATMOSPHERIC PRESSURE MEASUREMENTS

Speaking about atmospheric pressure measurements we must discuss units to measure it. They are following.

1. Pascal. (1 Pa, SI-unit.) It is equal to one Newton per one meter squared:

$$1Pa = 1N/m^2$$

   This unit is too low to measure atmospheric pressure, because normal atmospheric pressure is about 10^5 Pa.
2. Hectopascal, 1 HPa, non-system unit. 1HPa = 100 Pa.
3. Millibar, 1 Mb = 1HPa. It is quite old non-system unit, but atmospheric pressure is measured in millibars till now.
4. One millimeter of mercury column (1mm. m. c.). It isn't system unit, it appeared due to mercury barometers. As you know, 1mm. m. c. = 1,33 HPa.
5. One tor (Tor), the unit named in honor in Torichelly. 1 Tor = 1mm.m.c. It is used for low-pressure measurements only.

The devices for atmospheric pressure measurements are called *barometers*.

LIQUID BAROMETERS

All liquid barometers are based on Torichelly's effect. When a tube with a heavy liquid (e.g. mercury) is turned over a cup with the same liquid (see fig.13.1), there is vacuum above the liquid within the tube. The atmospheric pressure to liquid in the cup is equal to the weight of liquid within the tube. An altitude **h** of the mercury column depends on atmospheric pressure. To obtain this dependence we can write the equation:

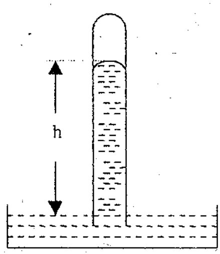

Fig.13.1.

$$P = \rho \cdot g \cdot h$$

Here **p** is atmospheric pressure, ρ is the density of liquid, **g** is the gravity acceleration.

Solving this equation for **h**, we get:

$$h = \frac{P}{\rho \cdot g}$$

The altitude **h** can be written on a scale near the tube.

Let's write the expression for sensitivity of liquid barometer:

$$S = \frac{dh}{dp} = \frac{1}{\rho \cdot g}$$

You see – the sensitivity is proportional to ρ inverted. The question is – why the mercury is used? The density of the mercury is the highest. So, the sensitivity is the lowest! Try to answer this question yourself.

The construction of the barometer is shown on fig. 13.1. It is named *cup barometer*. There is one peculiarity of this barometer. When atmospheric pressure changes, the mercury level within the tube changes, but the level in the cup changes too! It is undesirable, because the level in the cup is the point-reckon of the scale. To eliminate this error divisions with the length 0.98 mm. (instead of 1mm) divide the scale. Such a scale is named *compensated scale*.

Another construction of mercury barometer named *siphon-cup barometer* is shown on fig.13.2.

Here you can see the long tube with mercury and a short tube opened above. They are put into a skin bag. Below the skin bag there is the screw. The observer can rotate this screw and change the level in the long and on the short tube. The mercury level in the short tube must be got to the point-reckon. The mercury level in the long tube indicates the atmospheric pressure. Such a barometer hasn't compensated scale.

After reading the mercury level by scale an observer must apply some corrections to the results. There are three corrections to be applied for mercury barometer.

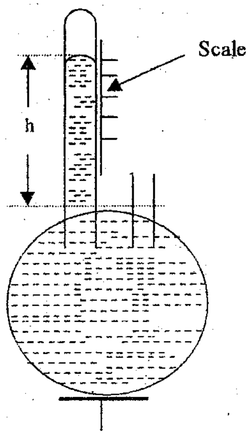

Fig. 13.2

1. The correction for temperature. The density of mercury depends upon temperature. Thus barometer data must be corrected to 0^0C. It can be done by using special tables or with the formula:

$$\Delta p = -l \cdot \alpha \cdot t$$

Here l is the altitude of mercury column, α is mercury expansion coefficient, **t** is temperature in centigrade.
2. The correction for the gravity acceleration **g**.
2.1. The correction for **g** changing due to altitude above sea level. It can be calculated with the formula:

$$\Delta p = -l \cdot \gamma \cdot z$$

Here **z** is altitude of the station above sea level, γ is constant coefficient ($\gamma = 2 \cdot 10^{-7}$ M^{-1}).
2.2. The correction for **g** changing due to latitude. Barometer's data must be corrected to 45^0 latitude. Let's write the formula for this correction:

$$\Delta p = -l \cdot b \cdot \cos 2\varphi$$

Here φ is the latitude of a station, β is the constant coefficient ($\beta = 2{,}05 \cdot 10^{-3}$).
3. Instrumental correction. Every barometer has its own instrumental correction. This correction is due to peculiarity of a device.

If we apply these corrections, we'll know the atmospheric pressure at the station. But to draw meteorological maps we have to calculate the pressure at the sea level. The meteorological maps are drawn for altitude **h** = 0. Certainly, we can do it with the barometrical formula, or using special table for every station.

DEFORMATION BAROMETER

The sensor of deformation barometer is a barometer capsule. It is shown on fig. 13.3.

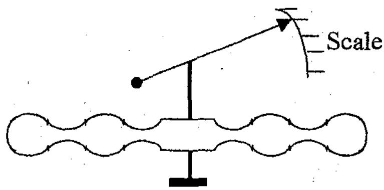

Fig. 13.3. Barometer capsule.

There is vacuum inside this capsule, so atmospheric pressure compresses it. But the material of these capsule walls is restoring. Thus the box compression depends on atmospheric pressure. We can read the data on the scale. Sometimes two or three capsules are connected in series. Such a sensor is named *sylphone*.

This barometer is very simple and convenient for using. It is named *aneroid*. But it has two sources of errors. Let's consider them.

1. Temperature error. Wall elasticity depends on temperature. Thus, if temperature rises, the capsule compression increases. To eliminate this error two methods can be applied.

1.1. Bimetallic compensation. Let's place the sylphone onto bimetallic plate (see fig.13.4).

When temperature changes, the bimetallic plate (2) moves sylphone (1) with a pointer up or down. The temperature error can be compensated by such a way. To correct the value of compensating movement there is a screw (3). It can be moved to the right or to the left. The length **l** of the bimetallic plate active part is changed so.

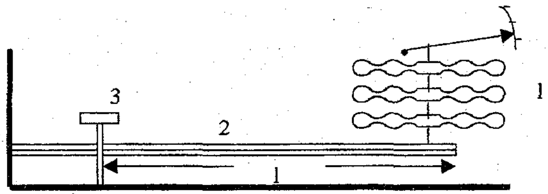

Fig.13.4. Bimetallic compensator.

1.2. Gaseous compensation. Sometimes there is a gas within the sylphone, but the pressure inside is very low. When temperature rises, the gas expanses. The expansion force compensates the compression due to the temperature error.

2. Hysteresis of the sylphone. The matter is that sylphone has permanent set. Thus, when pressure increases, aneroid underreads data, when pressure decreases, aneroid overreads (see fig.13.5).

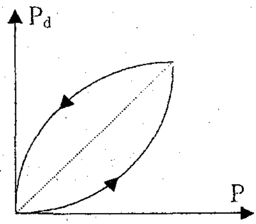

Fig. 13.5. Hysteresis of sylphone. $\mathbf{P_d}$ is pressure, read by the scale, **P** is real atmospheric pressure.

To eliminate this error observer has to knock the barometer with a finger. The pointer will move to another (right!) division.

VOCABULARY

Cup barometer – чашечный барометр
Point-reckon – точка отсчета
Siphon-cup barometer – сифонно-чашечный барометр
Screw – винт
Correction – поправка
Latitude – широта
Sylphone – сильфон

Lecture 14.

ACTINOMETRY MEASUREMENTS

Actinometry measurements are measurements of solar radiation fluxes. The importance of these measurements needn't be proved. Most important actinometry values are the following.

1. Direct solar radiation, **S**.
2. Diffuse radiation (or scattered sky radiation), **D**.
3. Accumulated radiation, i.e. the sum of direct and diffuse radiation, **S+D**.
4. Radiation balance, **B**, i.e. the difference of downward radiation and upward radiation.

Many methods can be suggested to measure these actinometry values. Some of these methods are listed in table 14.1. Let's discuss them.

Table 14.1.

N	Methods	Sensitivity	Wave-length range
1	Calorimetric method	Rather low	0...∞
2	Photoelectric method	Very high	1...6500 nm.
3	Photographic method	Very high	1...1200 nm.
4	Visual method	Rather high	400...750 nm.

Only one of these methods is capable to measure all wavelength radiation. That's why calorimetric method is chosen for actinometry measurements. The essence of this method is using a black body (or black plate), heated by radiation. The temperature difference of the black body and air is proportional to radiation flux. It is measured by thermopile for example. This method is used in all actinometry instruments (in Russia and abroad).

DIRECT SOLAR RADIATION MEASUREMENT

To begin with let's say a few words about absolute and relative instruments.

An absolute instrument doesn't involve a calibration. A measuring quantity is compared with another one, which value is known. For example to weigh a body we may put it into one cup of balance. Then we must equilibrate our balance with some weights, putting them to another cup. This is the *absolute instrument*, the absolute balance.

But there is another method of weighting. Suppose, there's a spring under the cup, and the cup is connected with a pointer. The weigh is transformed to an angle of a pointer by such a way. This is the principle of *relative instrument*, relative balance. Of course, relative instrument must be calibrated.

Now we'll study two instruments for measuring direct solar radiation. One of them is the absolute instrument. It is the *Angstrom's compensation pyrheliometer*. Compensation pyrheliometer is pictured on fig. 14.1.

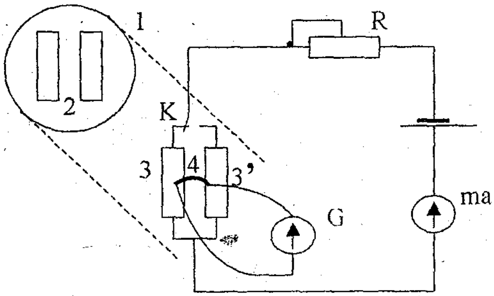

Fig. 14.1. Compensation pyrheliometer.

Here (1) is the tube with two right-angle holes (2) in the side, directed to the sun. One of these holes is open, another is closed. Sun radiation illuminates one of the right-angle black plates 3 or 3', placed on the bottom of the tube. So, one of these metal plates (3', for example) is heated by direct solar radiation. Current from the battery B heats another plate (3). This current may be changed with a variable resistance R and measured with a milliampermeter (ma). A thermocouple (4) shows the temperature difference of two plates. An observer makes such value of current i, that the temperature difference becomes zero. Thus the heat amounts to both plates (per second) are equal to each other. It can be introduced by equation:

$$\delta \cdot S \cdot s = i^2 r$$

Here S is direct solar radiation (in KW/m),

s is the square of plate,

δ is the coefficient of radiation absorption by plates (for black plates $\delta \cong 1$),

r is the resistance of plate.

Herefrom the expression on **S** can be easily obtained:

$$S = \frac{r}{\delta \cdot s} i^2 = K \cdot i^2$$

where K is a constant coefficient, which is known for the pyrheliometer.

To make the observations more accurate the key K is turned to the right position, the opened hole closes and the closed hole opens. Then the process of observation is made once more. The average result is calculated.

Now the Angstrom's compensation pyrheliometer is used only for calibration of actinometers.

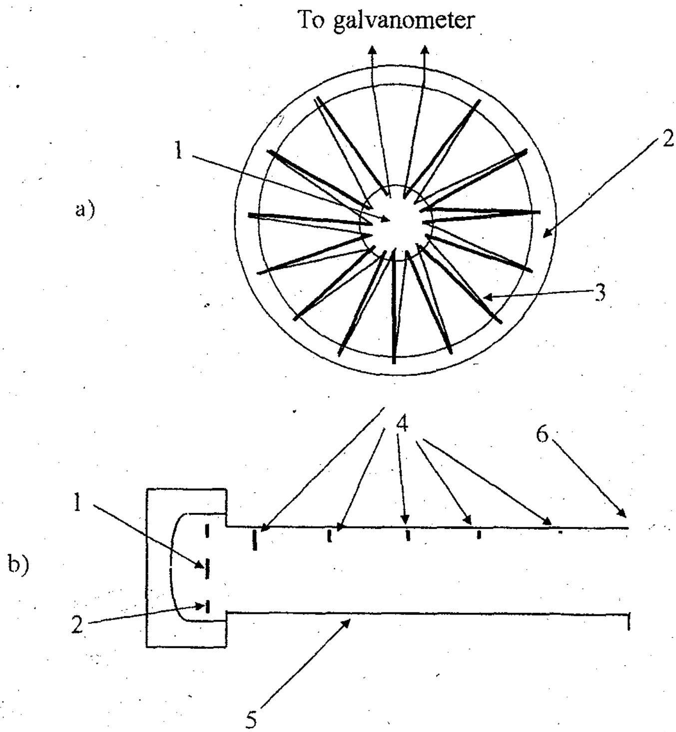

Fig. 14.2. Thermoelectric actinometer.

Thermoelectrical actinometer is another instrument for direct solar radiation measurement. It is a relative instrument. Thus it must be calibrated. But it is more convenient for every day measurements.

You can see the circuit of thermoelectric actinometer on fig.14.2.

Here (a) is the sensor of actinometer, placed to the special tube (b). This tube 5 is directed to the sun so that solar radiation irradiates the silver disk (1). Diaphragms (4) allow solar rays irradiate only the disk, but not the copper ring (2) that is in the shadow. Solar radiation heats the black surface of silver disk. Thus there is a temperature difference of silver disk and copper ring. This difference is proportional to direct solar radiation. It is measured by thermopile (3) with a galvanometer.

Direct solar radiation **S** can be calculated by expression:

$$S = K\,(N - N_0) \qquad (14.1)$$

Here K is a coefficient, it is constant for the actinometer; N is the number of divisions, pointed by galvanometer at the moment of measurement; N_0 is the number of divisions when actinometer is closed by cover. The coefficient K is determined for each actinometer at the factory and it is presented in calibration certificate.

DIFFUSE RADIATION MEASUREMENT

Diffuse radiation is measured by pyranometer. One may think, it is very easy - the disk (1) must be irradiated by light from the entire upper hemisphere, t. i. from the sky. But two main difficulties have to be solved.

1.To place the cold joins of thermopile to the shadow.

2. To eliminate the heat loses due to wind.

The first difficult is solved in the following manner. A sensor of pyranometer is the plate with white and black squares, like a chessboard (see fig. 14.5.).

Black squares are covered by soot; white squares are covered by magnesia. Soot absorbs whole spectrum of radiation, but magnesia absorbs only long-wave radiation. Consequently, the temperature difference of black and white squares is due to short-wave radiation.

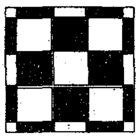

Fig.14.3. Pyranometer sensor.

As we know, diffuse radiation has maximum within short-wave range; that's why the sky is blue. Thus, to measure diffuse radiation we may measure temperature difference of black and white squares. It is measured by thermopile with galvanometer.

Using a transparent glass cap (1) (see fig. 14.4.) solves the second difficult.

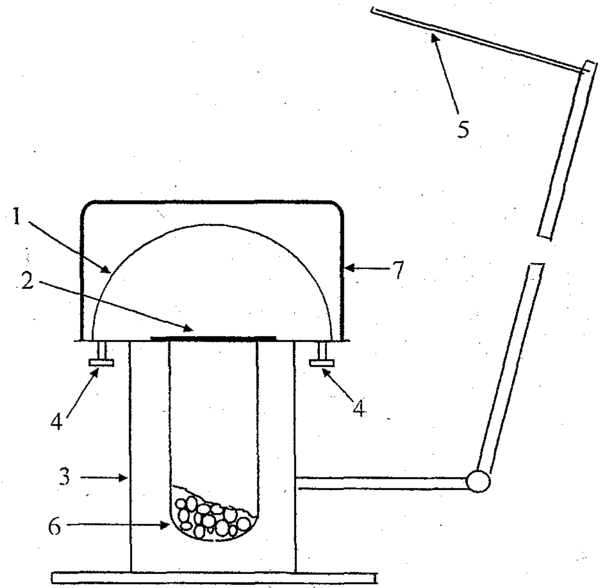

Fig. 14.4. Pyranometer. 1 – transparent glass cup, 2 – sensor, 3 – metal base, 4 – screws to connect the thermopile with galvanometer, 5 – shadow screen, 6 – drier, 7 – metal white cover.

The glass isn't transparent for wavelength less than 320 nm, but maximum diffuse radiation is within 425 - 450 nm range.

To measure diffuse radiation only the shadow screen (5) is used. It is metal disk, shadowing the sun from the pyranometer sensor. To measure accumulated radiation (S+D) the shadow screen must be displaced.

The diffuse radiation is calculated by formula:

$$D = K \cdot (N - N_0)$$

Here N and N_0 are number of galvanometer divisions at the moment of measurements (N) and with a metal cap (N_0). But the coefficient K depends on sun zenith angle θ. This dependence is plotted on fig. 14.5.

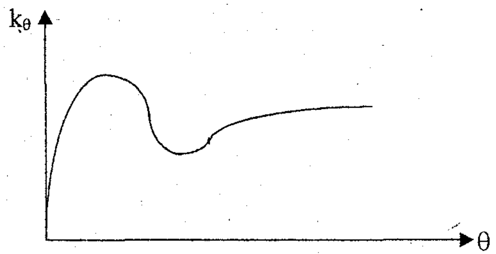

Fig.14.5.

To make calculations more convenient the coefficient K is divided by two ones: $K = k \cdot k_\theta$ where k depends on the pyranometer only, it is constant for the pyranometer. Coefficient k_θ depends upon only θ and the graph k (θ) is universal for all pyranometers.

VOCABULARY

Flux – поток (радиации)
Diffuse radiation – рассеянная радиация
Scattered radiation – рассеянная радиация
Accumulated radiation – суммарная радиация
Downward radiation – радиация, падающая сверху
Upward radiation – радиация, идущая снизу
Essence – сущность
Diaphragm – диафрагма
Copper – медь, медный
Calibration certificate – формуляр
Entire – полный, целый
Soot – сажа
Magnesia – магнезия
Drier – осушитель
Shadow screen – теневой экран, тенилка

Lecture 15.

RADIATION BALANCE MEASUREMENTS.

First of all I'd like to recall of the radiation balance definition to you. According to it, radiation balances the difference of radiation fluxes from upper hemisphere and from lower hemisphere. It is measured with a balansometer. The main part of balansometer is two black plates placed one above another (see fig. 15.1.). The temperature difference of two plates is due to the difference of radiation fluxes, i.e. due to radiation balance. This temperature difference is measured with thermopile.

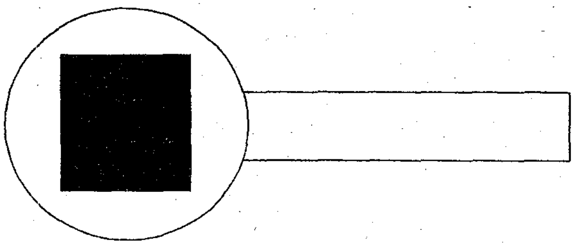

Fig.15.1. Balansometer.

Now let's consider the theory of balansometer. On fig. 15.2 you see three radiation fluxes directed to upper plate (2).

They are - direct solar radiation S, diffuse radiation D, and the emission E_A of atmosphere itself. On the other hand, there are three fluxes of heat from the upper plate. They are - convective heat flux $\alpha\cdot(T_1-\theta)$, the emission of upper plate to atmosphere $a\sigma T_1^4$, and the heat flux from upper to lower plate $\lambda/z\,(T_1-T_2)$.

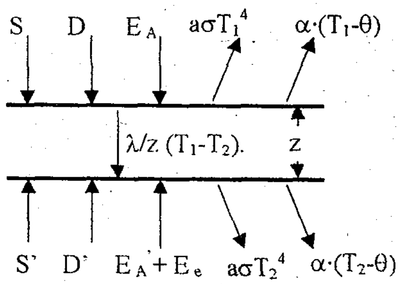

Fig.15.2

Let's express these fluxes (per square unit per one second). Then convective heat flux may be expressed as $\alpha\cdot(T_1-\theta)$, where $\boldsymbol{\alpha}$ is a heat exchange coefficient, T_1 is the temperature of the upper plate and $\boldsymbol{\theta}$ is the air temperature. Radiation flux is $a\sigma T_1^4$ where **a** is gray coefficient (for black plate a = 1), $\boldsymbol{\sigma}$ is Stephan-Boltzmann coefficient. The heat flux from upper plate to lower one is $\boldsymbol{\lambda/z\ (T_1-T_2)}$, where $\boldsymbol{\lambda}$ is the heat conductivity coefficient of the substance between plates, **z** is the thickness of balansometer, $\mathbf{T_2}$ is the lower plate's temperature. Certainly, the sign of this flux depends upon the sign of temperature difference $\mathbf{T_1-T_2}$.

Now let's speak about the lower plate. There are three radiation fluxes to this plate - solar radiation, reflected by earth surface **S'**, the radiation, scattered by atmosphere below **D'**, the emission of the atmosphere below and earth emission $\mathbf{E_A' + E_e}$. Of course, we must take into account fluxes of heat from the lower plate. They are – convective heat flux $\boldsymbol{\alpha(T_2-\theta)}$ and the emission of the lower plate $\mathbf{a\sigma T_2^4}$.

Suppose temperature of the plates $\mathbf{T_1}$ and $\mathbf{T_2}$ are constant. So, we have a stable state. Let's write heat balance equations for two plates. For the upper plate it is:

$$\delta\cdot(S+D+E_A)=a\sigma\cdot T_1^4+\alpha\cdot(T_1-\theta)+\frac{\lambda}{z}\cdot(T_1-T_2) \qquad (Б.1)$$

Here $\boldsymbol{\delta}$ is a radiation absorption coefficient.

And for lower plate:

$$\delta\cdot(S'+D'+E_A+E_e)+\frac{\lambda}{z}\cdot(T_1-T_2)=a\sigma\cdot T_2^4+\alpha\cdot(T_2-\theta) \qquad (Б.2)$$

Subtracting the equation (2) from (1) we get:

$$\delta\cdot(S+D+E_A-S'-D'-E_A'-E_e)=$$
$$=a\sigma\cdot(T_1^4-T_2^4)+\alpha\cdot(T_1-T_2)+\frac{2\lambda}{z}\cdot(T_1-T_2) \qquad (Б.3)$$

The expression in brackets in the left part of this equation is radiation balance **B** we are going to measure. On the other hand we may write:

$$T_1^4 - T_2^4 = (T_1^2 - T_2^2)(T_1^2 + T_2^2) \approx 2\overline{T}^2 (T_1 - T_2)(T_1 + T_2) \approx 4\overline{T}^2 (T_1 + T_2)$$

Here:

$$\overline{T} = \frac{T_1 - T_2}{2} \approx \Theta$$

Thus we get to equation for **B**:

$$\delta \cdot B = (T_1 - T_2)(\alpha + 4\Theta^3 \cdot a \cdot \sigma + 2\frac{\lambda}{z}) \qquad (5.4)$$

And the expression for **B**:

$$B = \frac{\alpha + 4a \cdot \sigma \cdot T^3 + 2\frac{\lambda}{z}}{\delta}(T_1 - T_2)$$

But the temperature difference ($T_1 - T_2$) measured by thermopile, may be expressed as:

$$T_1 - T_2 = \frac{i \cdot R_\Sigma^2}{e \cdot n}$$

Here **i** is the current through the thermopile, R_Σ is the total resistance of the circuit, **e** is specific EMF for the thermopile, n is the number of joins. Taking it into account, we can write the expression on i:

$$i = \frac{e \cdot n \cdot \delta}{R_\Sigma \cdot (\alpha + 4 \cdot a\sigma \cdot \Theta^3 + 2\frac{\lambda}{z})} \cdot B \qquad (5.5)$$

The sensitivity of balansometer can be expressed as:

$$\frac{di}{dB}=\frac{e\cdot n\cdot\delta}{R_{\Sigma}\cdot(\alpha+4\cdot a\sigma\cdot\Theta^3+2\frac{\lambda}{z})} \qquad (1\ 56)$$

Thus, to have a sensitive balansometer we must make the values **e** and **n** quite high. As to radiation absorption coefficient **δ**, it is approximately equal to 1 for black plates (δ≈1). In Janishevsky's balansometer n = 500.

The main source of errors for balansometer is the dependence of convective heat exchange coefficient on wind speed **α (V)**. Unfortunately glass cap isn't suitable for balansometer. The only may to eliminate this error is to make this value less than other terms:

$$\alpha << 4\cdot a\cdot\sigma\cdot\Theta^3+2\frac{\lambda}{z} \qquad (15.7)$$

For this purpose the thickness **z** is making so thin as possible (z ≈ 0.5 sm.). Doing so, we decrease the sensitivity. But this is the usual price for eliminating the source of errors.

As usual, we determine the radiation balance with the expression:

$$B = k\cdot(N - N_0),$$

where **k** is a coefficient depending upon wind speed.

VOCABULARY

Balansometer - балансомер
EMF – ЭДС, электродвижущая сила

Lecture 16.

CLOUD BASE ALTITUDE MEASUREMENTS.

There are 3 main methods to measure the altitude of a cloud base. They are following:

1. Visual method.
2. Balloon method.
3. Light - location method.

We'll study only the third method. It is most convenient and most accuracy method. The principle is that the light pulse goes from the transmitter to the cloud and being reflected returns to the ground surface. The time of light travelling depends upon cloud altitude **H**. Thus **H** can be calculated with the formula:

$$H = \frac{c \cdot \tau}{2} \qquad (6.1)$$

But the time τ is very low ($10^{-5} - 10^{-6}$s). So, it'll be very difficult to measure it. Fortunately, modern devices can do it.

Two main devices are used now in Russia for cloud base measurements. They are cloud altitude meter (измеритель высоты облаков ИВО-1м), and cloud altitude register (регистратор высоты облаков РВО-2м). We'll study the device ИВО-1м.

CEILOMETER ИВО-1м.

The ceilometer ИВО-1м is based on light-location method. The most important element in this device is cathode-ray tube (CRT). Thus let me explain it to you. Cathode-ray tube is drawn on fig. 16.1.

Here (1) is cathode, (2) is electrode-modulator, (3) is the accelerate net, (4) is focusing electrode, (5) are vertically deflecting plates, (6) are horizontally deflecting plates, (7) is anode, (8) is the screen, covered by phosphor. Electrons, flying from cathode to anode, are focused by electrode (4) so, that we can see a light-point on the screen. But the electron flux goes between vertically deflecting plates (5) and between horizontally deflecting plates (6).

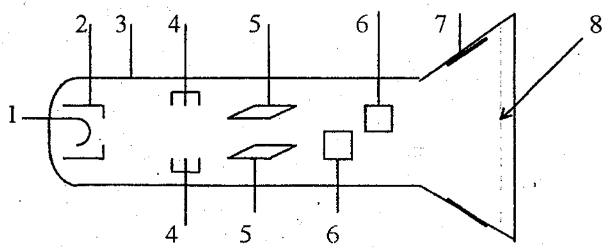

Fig.16.1. Cathode-Ray Tube (CRT).

Suppose, a voltage is there on the plates (6). The electron flux is deflected to positive charged plate, and the light-point on the screen deflects to the same side. Now suppose a voltage on horizontally deflecting plates changes with a saw-tooth law (see fig. 16.2 (1)).

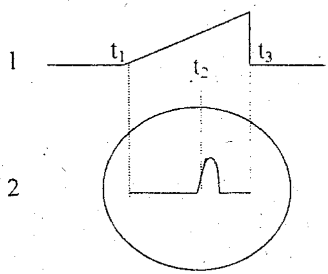

Fig. 16.2. The scanning pulse (1) and the picture on the screen (2).

The light-point on the screen moves to the right and we'll see a horizontal line (2). Here $\mathbf{t_1}$ and $\mathbf{t_3}$ are moments of the beginning and the end of this pulse. It is named the *scanning pulse*.

Now, let $\mathbf{t_1}$ be the time of light emission by the transmitter. At the moment $\mathbf{t_2}$ cloud-reflecting light returns to the receiver. The shot voltage pulse is applied to vertically deflecting plates at this moment. The electron flux deflects up and we'll see the vertical pulse on the screen (fig. 16.2(2)). It is named *cloud pulse*.

Now we understand - if cloud altitude is high, the difference $\mathbf{t_2}$-$\mathbf{t_1}$ is quite high too, and the distance on the screen up to cloud pulse is long. Thus the position of cloud pulse on the screen depends upon cloud altitude.

The matter is that electron flux has a very high speed inside the tube, and the mass of electrons is negligible. Thus the CRT is an inertialess instrument for time measurement. The duration of scanning pulse t_3-t_1 can be very short (10^{-5}s or less).

Now let's consider the block-diagram of the ceilometer ИВО-1м (see fig. 16.3.)

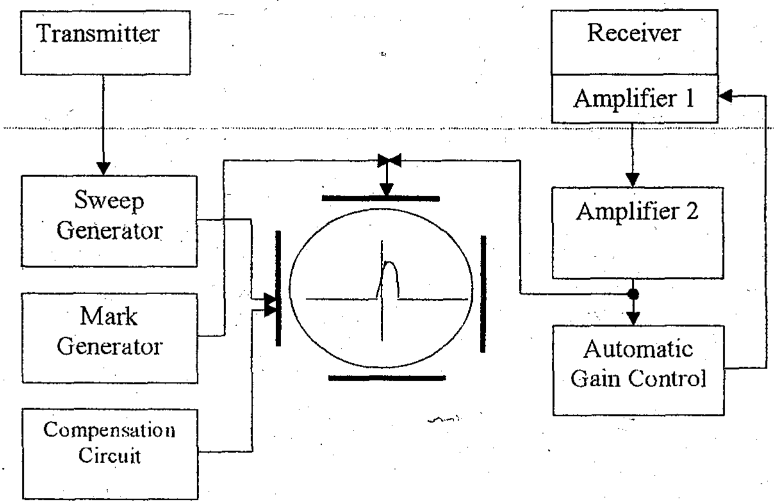

Fig. 16.3. The block-diagram of the ceilometer ИВО-1м.

The *transmitter* is the gas-filled lamp, placed to focal point of a dished mirror. The light pulse of this lamp has duration about 10^{-6} s. When the transmitter is on, the lamp flashes with a frequency about 20 Htz. The transmitter is oriented to zenith. Certainly transmitter is placed outdoors, on the meteorological square. When the lamp flashes, the light pulse goes to the cloud. At the same moment the electric pulse goes from transmitter to sweep circuit, placed in operating block. The sweep circuit generates the scanning pulse. The scanning pulse goes to horizontally deflecting plates of CRT.

The *receiver* is a photomultiplier, placed to focus of a dished mirror too. As well as the transmitter, the receiver is placed on meteorological square.

The light pulse, reflected by cloud, is received by photomultiplier. Here it is transformed to electric pulse. But it is very faint. To make it high enough there is an amplifier 1 in receiver. Being amplified, electric pulse goes to amplifier 2, placed in operating block. After the amplifier 2 this pulse comes to vertically deflecting plates of CRT. The cloud pulse appears on the screen (see fig. 16.2.).

But how can we measure the position of the cloud pulse on the screen? To do so there is a *compensation circuit* in the operating block. It is a potentiometer. We can change a direct voltage on the horizontally deflecting plates, rotating the handle of this potentiometer. The picture on the screen will move to the left. Cloud pulse will move too. Let's place the leading edge of the pulse to the middle of the screen (vertical black line on the screen). Consequently, the angle of the potentiometer handle is the measure of cloud base altitude. If cloud altitude is high, the cloud pulse is far from the middle of the screen, and we have to rotate the handle to a high angle for placing the cloud pulse at the middle of the screen.

But the amplitude of cloud pulse depends upon cloud base altitude. It's not convenient. To make the pulse amplitude constant there is the special block, named *automatic gain control* (AGC). If the pulse amplitude is high, the AGC block makes amplifier 1 to reduce the gain.

The *mark generator* is used for the test of the device. During the test this block is on. It generates short electrical pulses. The frequency of these pulses is 1.5 MHz. An observer can see these pulses on the screen. Rotating the potentiometer handle, he places these pulses in turn to the middle of the screen and writes the angle of the handle. Then he compares his data with a calibration certificate and corrects the device.

This device is very convenient. It takes 10-15 s to measure cloud altitude with it. The cloud altitude can be measured at the range from 30 m to 1500 m.

OZONE MEASUREMENTS

Ozone is one of the most important atmospheric gases due to its property to absorb ultraviolet radiation. Ozone has absorption band from 270 to 330 nm. This ultraviolet radiation is very dangerous for all alive over the Earth. On the other hand now there are "ozone holes" in ozonosphere, thus we have to observe ozone amount as carefully as possible.

As you know, ozonosphere has the altitude from 10 to 50 kilometers above the earth surface. Of course, we can measure it with special sounds, flying at the ozonosphere. But the most interesting for us is the total ozone amount in vertical atmospheric column. Let's imagine all the ozone is near the earth surface at normal atmospheric pressure and 0C temperature. Then the thickness of ozone layer would be about 0.3 sm. Thus, the total amount of ozone can be measured in centimeters - it is the thickness of ozone layer, reduced to earthbound conditions. We'll use Dobson's units - 1 Dn = 10^{-3} sm. So, normal ozone amount is about 300 Dn.

For measurements of total ozone amount, the property to absorb ultraviolet radiation can be used. Let's measure the radiation flux from the sun (or the moon) within ozone absorption band. It depends upon ozone amount. Professor Gushchin constructs the device, based on this principle. It is named ozonometer. The block-diagram of Gushchin's ozonometer is drawn on fig.16.4.

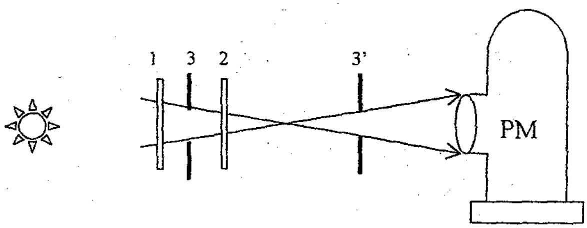

Fig.16.4. Ozonometer.

Here (1) is quartz glass, (3) and (3') are diaphragms, (2) is light filter, and (PM) is a photocell or a photomultiplier. The electric signal from photomultiplier must be amplified. After the amplifier it can be measured with a scale instrument.

But there are three difficulties to measure the ozone amount with the ozonometer.

1. The aerosol's influence. Aerosols absorb solar radiation too, but this absorption is non-selective.

2. The temperature influence. The thing is that light filter's properties depend upon temperature.

3. Sun zenith angle influence.

Let's solve these problems.

1. The aerosol's influence. To solve this problem we'll use two light filters. The first light filter transmits the ultraviolet radiation within ozone absorption band (300 nm). This radiation is reduced both by ozone and by aerosols. Let's denote the measured signal J_1. After that the second filter must be placed instead of the first. It transmits the ultraviolet radiation at the bound of ozone absorption band (327 nm). Aerosols reduce this radiation, but ozone absorption is negligible. We'll denote the measured signal J_2. The ratio $\frac{J_1}{J_2}$ depends only upon ozone amount.

2. The temperature influence. This problem is solved with the coefficient k_t, we'll multiply the ratio $\frac{J_1}{J_2}$. Of course, k_t depends upon temperature.

3. Sun zenith angle influence. The thing is that the length of the light way in the ozonosphere depends upon sun zenith angle Θ. (See fig 16.5.).

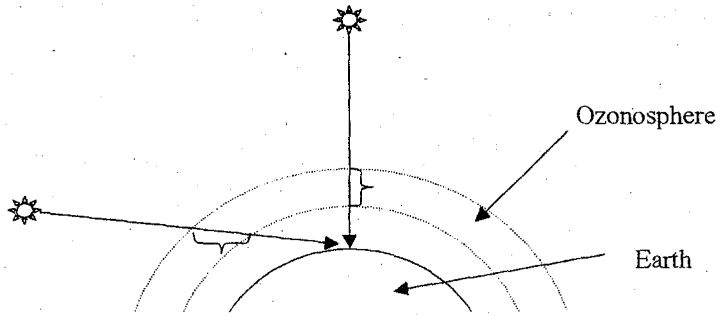

Fig. 16.5.

To solve this problem we'll use the diagram (fig. 16.6). After calculating the value
$\frac{J_1}{J_2} \cdot k_t$, the diagram is used for ozone total amount determination.

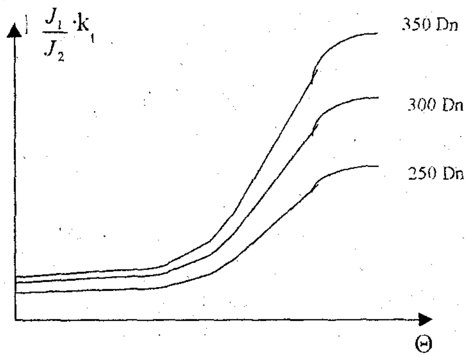

Fig. 16.6

VOCABULARY

Cathode-ray tube (CRT) – электронно-лучевая трубка (ЭЛТ)
Phosphor – люминофор, фосфор
Flux – поток, пучок (электронный или световой)
Deflect – отклонять
Saw-tooth law – пилообразный закон, закон строчной развертки
Scanning pulse – импульс развертки
Transmitter – передатчик
Duration – длительность (импульса)
Sweep generator – генератор развертки
Automatic gain control (AGC) – автоматический регулятор усиления (АРУ)
Gain – коэффициент усиления
Dished mirror – вогнутое зеркало
Concave mirror – вогнутое зеркало
Flash – вспыхивать
Faint – слабый (об электрических величинах)
Leading edge – передний фронт (импульса)
Calibration certificate – формуляр (документ, в котором отражается техническое состояние прибора и его изменения в процессе эксплуатации)
Absorption band – полоса поглощения
Earthbound conditions – приземные условия

Lecture 17.

ANEMORUMBOMETER M-63.

Anemorumbometer M-63 is a remote device for wind speed and direction measurements. The following values can be measured by it:

1. A momentary wind speed, that is the wind speed at the observation moment.
2. An average wind speed, that is the wind speed, averaged for 10 minutes.
3. A maximal wind speed at any time interval, e.g. for 10 minutes.
4. A wind direction.

This device consists of three blocks - a transducer, a measuring unit and a power unit. We'll not study the power unit - it's a usual rectifier with a transformer, which steps down the voltage from 220 to 12 volts. But we'll study the transducer and the measuring unit, which consists of three channels: a momentary wind speed channel, an average wind speed channel and a wind direction channel.

TRANSDUCER.

A transducer is placed on the top of the mast. It looks like a small airplane (see fig. 17.1). There is a propeller (1), rotated by wind, and a vane (2). The position of vane depends upon the wind direction. Then, there are two gears (3 and 3'), rotated by propeller. Of course, its angular velocity depends upon wind speed. The thing is that the number of the teeth of gears 3 and 3' are equal, so their angular speeds are equal too. And there is the copper cup 4 with the ferrite rod 5 and 5'. Three pulsers are placed under gears - P_r, the *reference* pulser, P_b, the *basic* pulser and P_s, the *shifted* pulser. When ferrite rod is above the pulser, it generates a current pulse.

So, the frequency of pulses depends upon wind speed. But there are three series of pulses - the reference series, the basic series and the shifted series (see fig. 17.2.). The frequencies of these series are equal.

Thus, to measure the wind speed we have to measure the frequency of any pulse series. But how can we measure the wind direction? To solve this problem I'd like to draw your attention to the phase shift between **r**- and **s**- or between **b**- and **s**-series.

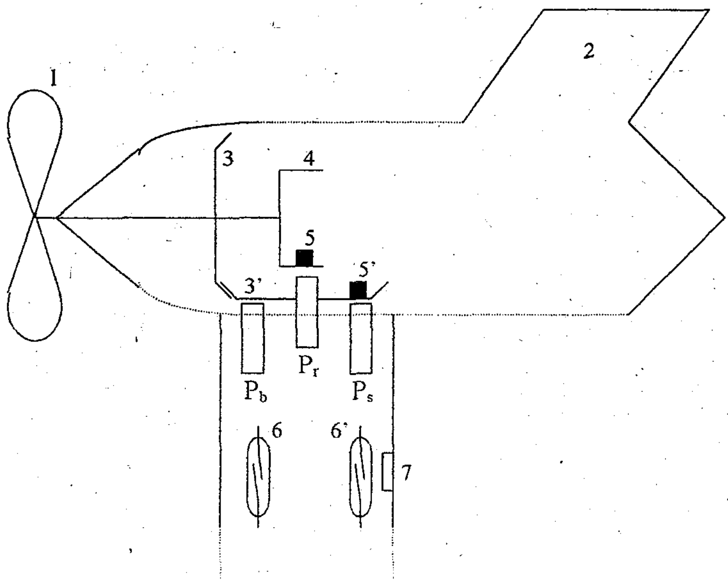

Fig. 17.1. Transducer.

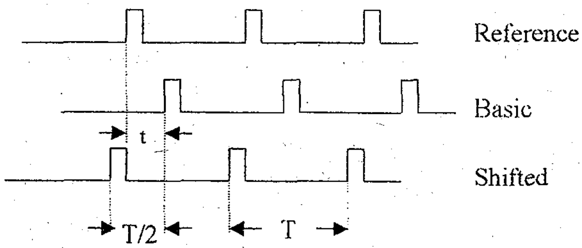

Fig. 17.2. Reference, basic and shifted series of pulses.

When the wind has north direction, **r** and **s**-pulses are generated simultaneously; the pulse shift **r-s** is equal to zero. When the wind changes direction, the vane rotates and the gear 3' rotates too. Now ferrite rod 5' has another position when the rod 5 is above the pulser P_r. Thus, the pulse shift between **r**- and **s**-series takes place and it depends upon wind direction. To measure it we have to measure the ratio $\frac{t}{T}$ (see fig. 17.2.), because $\varphi = \frac{t}{T} \cdot 360^0$.

But the pulse shift between **b** ant **s**-series is equal to 180^0, it is constant. So, we can measure the pulse shift **b-s**, it depends upon wind direction too.. Doing so, we must take another scale, it is shifted to 180^0.

Now let's study the pulser arrangement. The pulser circuit is showed on fig. 17.3,b.

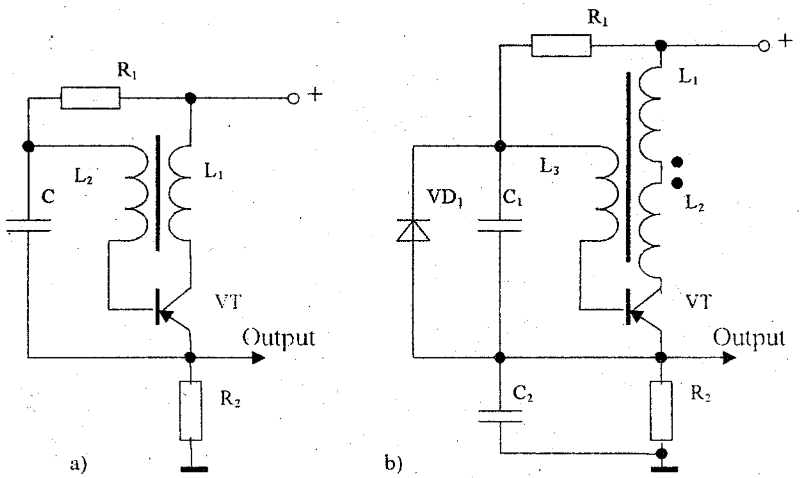

Fig.17.3. Blocking-generator (a) and pulser (b).

You see, it is like a *blocking-generator* (fig. 17.3,a) The most important detail of blocking-generator is a tuned circuit L_2-C. The oscillations from this tuned circuit are amplified with the transistor VT and turn to circuit again with the transformer L_1-L_2. As a result, we have a sinusoidal current signal from the output resistor R.

Now see the pulser circuit (b). There are two coils in the first transformer winding - L_1 and L_2. The inductance $L_1 = L_2$. But the thing is that they are performed in the opposite directions. Due to this the transformer feedback between the first winding - L_1 and L_2 - and the second winding L_3 is equal to zero! Blocking-generator doesn't generate the signal.

But when the ferrite rod is above the transformer the inductance L_1 increases. The positive feedback between L_1 and L_3 is taking place for a moment and blocking process appears (see fig.17.4, a).

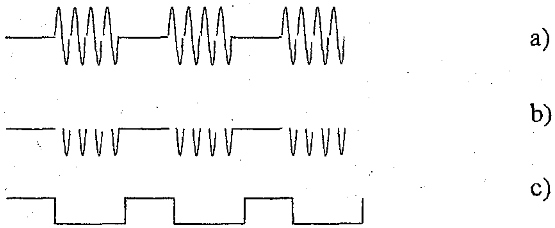

Fig.17.4. Voltage patterns.

The diode VD shunts one half-cycle of these oscillations (fig.17.4, b) and the capacitor C_2 detects this signal (fig.17.4, c). Thus, the negative pulse appears every time when the ferrite rod is above the transformer. Pay attention - these pulses are negative!

To make these pulses positive these are three formers (F_r, F_b and F_s) in the measuring unit. Of course, the measuring unit is connected with the transducer by cable (fig. 17.5.)

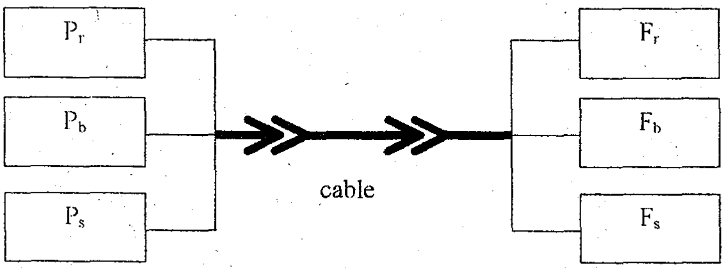

Fig. 17.5. The pulsers (P_r, P_b, P_s) and the formers (F_r, F_b, F_s), connected by cable.

AVERAGE WIND SPEED CHANNEL.

To determine average wind speed for 10 minutes the total number of pulses for this period must be calculated. Thus, two problems must be solved:

1. To pass the pulses to the channel for 10 minutes - not more, not less.
2. To calculate these pulses and average wind speed.

All these problems can be solved by the circuit (see fig.17.6). Positive pulses from the reference pulse former F_r come to the key K, closed by observer. In 10 minutes the timer opens the key K and pulses don't go to the channel. Thus, the first problem is solved with the timer and the key.

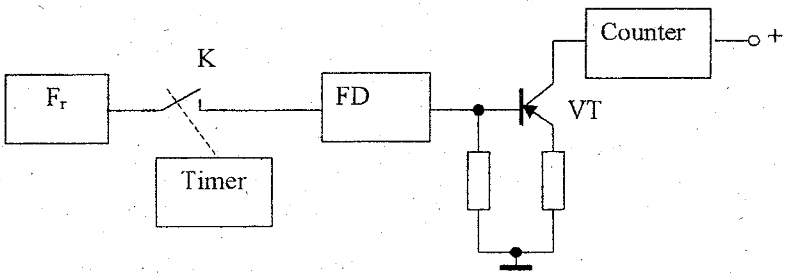

Fig. 17.6. The block-diagram of average wind speed channel.

The second problem is solved by the counter. When pulses come to transistor VT, it becomes on and a current from the source goes thought the counter. The pointer moves along the scale to one division.

So, every pulse causes the scale needle movement to one division.

To make the observation more convenient there is a *frequency divider* FD. Suppose, the pulse frequency on the input of divider is **f**, then the frequency on the output is **f/k**, where **k** is divider coefficient. It is chosen so that the total number of the output pulses for 10 minutes is equal to average wind speed (measured in meters per second), multiplied by 10. Thus, the observer must wind up the timer, wait 10 minutes, look at the scale and determine the average wind speed, dividing the number of division by 10. For example, if the number of divisions is 48, the average wind speed is 4.8 m/s.

In modern digital devices M-63m-1 microminiature modules are used. There is the digital indicator of average speed. We'll study such modules quite soon.

MOMENTARY AND MAXIMAL WIND SPEED CHANNEL.

Before the explanation of this channel I'd like to recall you one of the most important circuit in electronics. It is named *bistable*. Sometimes it's named *flip-flop*. This circuit is drawn on fig. 17.7.

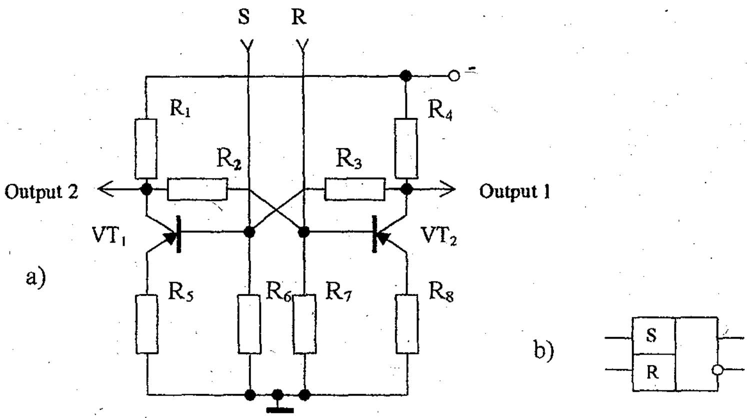

Fig. 17.7. A bistable (or flip-flop) (a) and its logic symbol (b).

The transistor (VT_1 or VT_2) of p-n-p type may be on (the collector is connected with the emitter) when base is charged negatively. And it is off (that means, the collector isn't connected with the emitter) when base is charged positively. Suppose, VT_1 is on. Then its collector is connected with a positive pole (it is grounded here) and positive charges go through R_2 to VT_2 base. Consequently, it is off. Thus its collector isn't connected with the emitter, but it is connected with the negative pole through R_4. Negative charges go to VT_1 base through R_3. Thus VT_1 is on, VT_2 is off. This state is stable.

Now let positive pulse go to VT_1 base (**S**-input). VT_1 turns off, the potential of its collector becomes negative. Negative charges go to VT_2 base though R_2 and VT_2 turns on. The potential of VT_2 collector becomes positive; positive chargers go to VT_1 base through R_3. Thus VT_1 remains being off even when the positive pulse finishes. We'll say, the flip-flop changes state, or *sets*. When it changes state again, and negative potential is on **S**-input, we'll say the flip-flop *resets*. (That's why **S** and **R**-inputs are called so!).

Now let's consider the circuit of a momentary and maximal wind speed channel. It is drawn on fig. 17.8.

For measuring momentary wind speed we'll use the basic pulse series. So, right-angled positive pulses passes through capacitor-diode circuits C_1 - VD_1 and C_2 - VD_2.

After passing the capacitor right-angled pulse transforms to two momentary pulses (see fig. 17.9,a,b). Then diode passes only positive pulse (fig.17.9, c). Thus positive momentary pulses come to S- and R-inputs of flip-flop and the flip-flop sets.

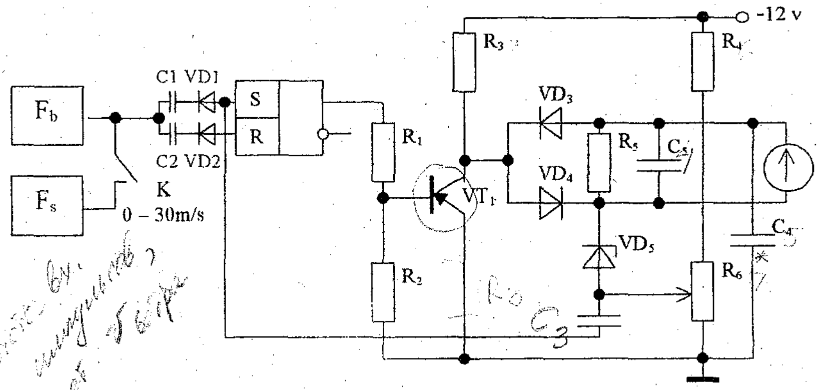

Fig.17.8 Momentary and maximal wind speed channel.

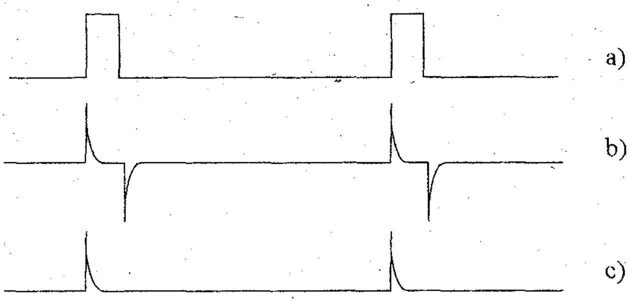

Fig.17.9

Positive charges go through R_1 to VT_1 base and transistor VT_1 turns off. Negative charges from the current source cannot pass through it (it is off!) and pass through R_4 - VD_3 – C_4 to the ground (the ground is connected with the positive pole here). The capacitor C_4 charges; its upper plate charges negatively. Thus its negative potential increases and soon potential regulator VD_5 breaks down. The negative pulse goes through C_3 to S-input of flip-flop. The flip-flop resets. The negative charges appear on the output of flip-flop, they go through R_1 to base VT_1. VT_1 turns on. The capacitor C_4 finishes the charging and begins to discharge through the circuit: C_4-VT_1 (emitter-collector)-VD_4 - C_4. Thus C_5 and C_4 are connected in parallel. But the capacity $C_5 >> C_4$, and C_4 discharges to C_5. A low potential difference appears on C_4.

The next pulse repeats all these processes. The potential difference on C_5 increases. But C_5 discharges through R_5 and soon the potential difference (or voltage) on C_5 stabilizes. It's easy to understand - the higher is the pulse frequency, the more is the voltage on C_5 at stable state. It is measured by scale instrument.

The passive pointer (the scale pointer without a spring) shows a maximal voltage, which corresponds to the maximal wind speed.

The usual scale has divisions from 0 to 60 m/s. But to determine the wind speed more accuracy there is another scale - from 0 to 30 m/s. To use it the observer must press the button **K** "0-30". Then the shifted pulses go to the channel in addition to basic series. The pulse frequency increases by two times. The voltage on C_5 increases by two times too.

To verify this channel there is a control block inside the measuring block. It generates pulses with constant frequency (about 30-35 Hz). The observer turns on this block and compares the average speed channel and momentary speed channel indications. If there is a difference between these indications the resistor R_6 must be regulated.

I'd like you to answer the question - why the voltage on C_5 depends on the position of the variable resistor R_7? Try to do it yourself.

VOCABULARY

Measuring unit – измерительный блок
To step down the voltage – понижать напряжение (обычно с помощью трансформатора)
Transducer – датчик
Mast – мачта
Gear – шестерня
Pulser – импульсатор, генератор импульсов

Reference – опорный
Basic – основной
Shifted – сдвинутый
Arrangement – устройство (какого-либо блока, механизма и т.д.)
Blocking-generator – блокинг-генератор, устройство для генерации синусоидально меняющегося напряжения
Transformer – трансформатор
Tuned circuit – колебательный контур
Coil – катушка (обмотка провода)
Winding – обмотка (то же, что катушка)
To perform – наматывать
Inductance - индуктивность
Feedback – обратная связь
Shunt – шунтировать, замыкать
Frequency divider – делитель частоты
To wind up the timer – завести часовой механизм
Bistable (flip-flop) – триггер
Potential regulator – стабилитрон, элемент, который пропускает ток только при превышении напряжением определенной величины (стабилитрон «пробивается»)
Potential regulator breaks down – стабилитрон пробивается

Lecture 18.

WIND DIRECTION CHANNEL.

Last lecture we understood that if we want to measure the wind direction we must measure the reference and basic series phase shift $\varphi = \frac{t}{T} \cdot 360^0$, where T is a pulses period (see fig.17.2). For this purpose the circuit (fig.18.1) is used.

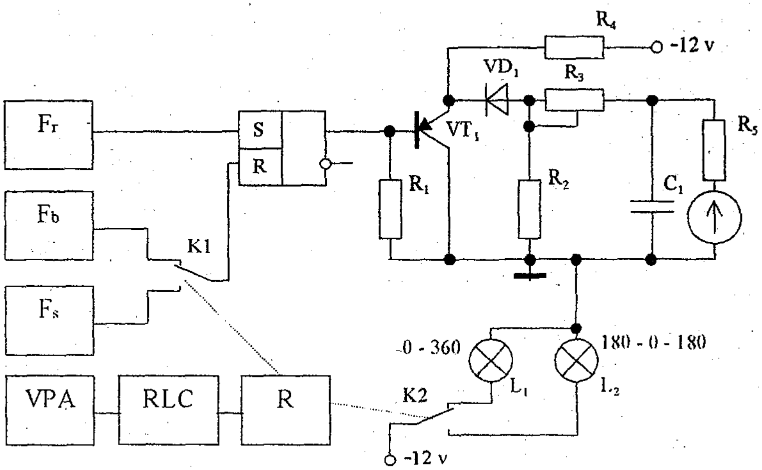

Fig. 18.1. Wind direction channel. VPA - vane position annunciator; RLC - relay lock circuit.

When relay contact K1 has the upper position, basic pulses go to R-input of flip-flop, and reference pulses go to S-input. Suppose, reference pulse is the first. The flip-flop sets and the positive potential from its output turns off the transistor VT_1. Then (after the time **t**) basic pulse comes to R-input. The flip-flop resets and negative potential turns on the transistor VT_1. Thus VT_1 is off during the time **t** only. What's happened with the others elements of the circuit during this time?

When VT_1 is off, the current can't go through it, it goes through R_4 – VD_1 – R_3 and charges the capacitor C_1. The capacity C_1 is quite high, it charges slowly. It discharges during the time **T-t** through R_3 – R_2. (Here **T** is the period of pulses.) Then it charges again and so on. The voltage on C_1 increases, but soon it becomes constant – charging and discharging processes becomes equal. This is the stable state. It's easy to understand -

the voltage on C_1 in stable state is proportional to ratio t/T, and if t = T it is maximal. Thus the phase shift **r-s** can be measured with the scale instrument.

But when the wind has the north direction, phase shift is equal to zero (t = 0) or 360^0. (t = T). If the vane hunts about an equilibrium north position, the capacitor C_1 averages low and large charge doses and the pointer shows south direction instead of north! To avoid such a terrible mistake, we can use another pare of pulse series -reference and shifted series. Certainly, another scale must be used - with the north in the middle of the scale. But how these series can be changed? It can be done with the relay R, switching contacts K1 and K2. The relay R is operated with the voltage, switching by two hercons 6 and 6' and the magnet 7 (see fig.17.1.). This construction
is named VPA - vane position annunciator (see fig.18.1.). When one of hercons is on, relay picks up and contacts K1 and K2 are at the lower position. Pare **r-s** is used and the green lamp L_2 is on. The observer knows - the scale **180 - 0 - 180** is used. When the wind changes the direction, another hercone is on, contacts K1 and K2 move to the upper position, pare **r-b** is used and the red lamp L_1 is on. The scale **0 - 360** is used. The relay is locking by RLC (relay lock circuit) until another hercone would be on.

To test this channel the negative voltage from control block is given to flip-flop R-input. The flip-flop sets and VT_1 is off all the time. Thus we can say, t = T, or t/T = 1, or $\varphi = 360^0$.

The pointer must show 360^0. If it shows another value, the observer regulates the variable resistor R_2, varying the current for charging C_1. Of course, the voltage on C_1 varies too.

METEOROLOGICAL VISIBILITY RANGE MEASUREMENTS.

Suppose a black body is seen on celestial background. The angular size of the body is 20'. The distance from the body to observer is named *meteorological visibility range* (MVR) if the observer can distinguish this body on celestial background. To define the term "distinguish" let's talk about *contrasts*.

The term "*contrast*" means the ratio:

$$K = \frac{J_b - J_o}{J_b} \qquad 18.1$$

Where J_b is the background luminance, J_o is the luminance of body. It's clear, the value **K** can vary from 0 (if $J_b = J_o$) from 1 (if $J_o = 0$). The minimum contrast that the man's eye can distinguish is named the contrast sensitivity threshold (ε):

$$\text{im} \quad K = \varepsilon \qquad 8.2$$

Usually ε is about 0.03 - 0.05, or from 3% to 5%. Now we can determine the term MVR:

MVD is the distance to black body with 20' angular size, when the visual contrast of this body and celestial background is equal to ε=(3-5%).

There are three methods of MVD observation. They are following:

1. Visual method.
2. Instrument-visual methods.
3. Instrument methods.

We'll not study visual method. It is very simple. But we'll say a few words about instrumental-visual methods. And we'll study two devices for measuring MVD by instrument methods.

POLARIZATION VISIBILITY RANGE INSTRUMENT M-53.

The instrument M-53 for visibility distance measurements is rather old device. But it is used till now and we have to study it. It is rather simple.

The device M-53 includes two polarizers (2 and 3, see fig.18.2.). (1) is a transparent glass. One of the polarizers, 2 is stationary, another (3) can be rotated with a handle 4. The object (usually a black box) is observed on a background (a long distance forests, a mountain and so on).

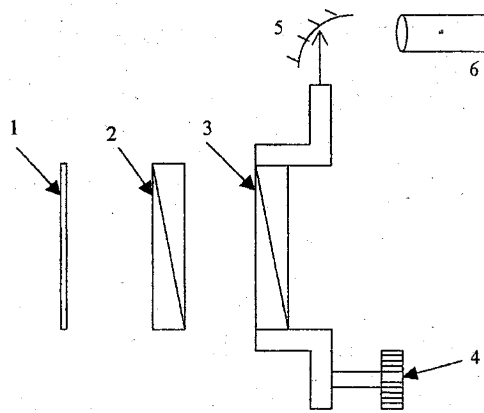

Fig.18.2. The optical diagram of M-53

After the first polarizer two light fluxes, from the object and from background, become polarized. The next polarizer (3) resolves these two fluxes into components (see fig.18.3.). There are two perpendicular components for each flux - so called "*usual*" and "*unusual*".

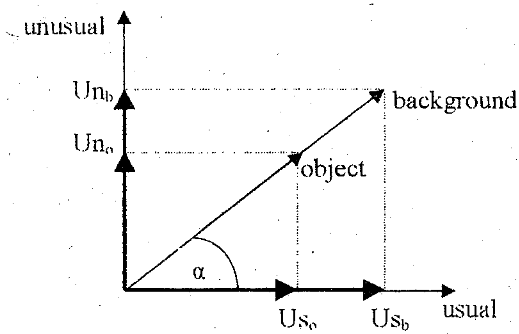

Fig.18.3

Thus, the observer sees four fluxes - usual from the object, (Us_o), usual from the background (Us_b), unusual from the object (Un_o) and unusual from the background (Un_b). Let's chouse two of them - Us_b and Un_o (or Us_o and Un_b). Their intensities are different. If the weather is fine and the air is transparent, the difference of these fluxes is high. But if there is a fog, the difference of these fluxes is low, or they are equal. On the other hand, rotating the polarizer 3, we can change the difference of these fluxes (changing the angle α on fig.18.3.).

The observer rotates the handle 4, making these fluxes equal. The pointer 5 shows a division on the scale. The observer can see the scale through the objective (6). The MVR can be determined with special tables.

This method can be used only at daytime. At night the MVR can be measured with another device - nephelomer M-71. But now this nephelomer is not used, because there are modern devices – visibility range registrar РДВ-3 (регистратор дальности видимости РДВ-3) and pulse photometer ФИ-1 (фотометр импульсный ФИ-1). Now the pulse photometer ФИ-2 is engineered.

VOCABULARY

Annunciator – сигнализатор
Hunt about – колебаться около…
Hercon – геркон
Relay picks up – реле срабатывает
Relay is locking – реле заблокировано
Relay lock circuit – схема блокировки реле
Meteorological visibility range (MVR) – метеорологическая дальность видимости (МДВ)
Contrast sensitivity threshold – порог контрастной чувствительности
Polarizer - поляризатор

Lecture 19.

VISIBILITY RANGE REGISTRAR РДВ-3.

Visibility range registrar РДВ-3 is intended for MVR measurements at weather situation when MVR is from 200 to 6000 m. It includes a light source (a usual lamp) and a reflector placed at 100-m distance from a lamp. A luminance of reflected light beam depends on transparency of atmosphere, or on MVR. Such a devices are called *transmissometers*.

The transmissometer РДВ-3 is based on the following principle. There are two light beams in this device. One of them, which passes through the 100 m-layer of the air and again, being reflected, is called *sounding beam*. Another beam passes within the device box only, but it is regulated with the diaphragm. It is called *comparative beam*. The thing is that comparative beam is regulated automatically so, that its luminance is equal to sounding beam luminance! Thus, when diaphragm is small, the luminance of the comparative beam is small two; therefore the sounding beam luminance is low. It means, MVR is low. The diaphragm is connected with the scale and the observer can read the MVR value with it. There is the automatic recorder of MVR.

But how does this automatic system operate? To answer this question we have to consider two diagrams. One of them - the optical system - is drawn on fig.19.1. Here the light beams are shown by the arrowy lines. The light beam from the lamp passes through objective $\mathbf{O_1}$ and becomes parallel. The semitransparent plate **STP** divides this beam to two beams. The sounding beam passes through objective $\mathbf{O_2}$. It is focused to the edge of disk-modulator DM. The disk-modulator, rotated by motor **M**, has the form, pictured on fig.19.2. The sounding beam passes through lower edge of this disk, the comparative beam – through the upper edge. You see, when the sounding beam is interrupted by the big tooth of the disk, the comparative beam passes through the small teeth, and on the contrary. Thus, disk-modulator passes these beams by turns. On the other hand, each beam is interrupted by small teeth. The frequency of beam oscillation (due to small teeth) is 1780 Hz. It is called modulation frequency. The frequency of interchanges of sounding and comparative beams is 12 times less, 148 Hz.

After the disk-modulator the sounding beam passes through objective $\mathbf{O_3}$ and becomes divergence with a small angle. Then, passing through the glass **G** it goes to reflector **R**. Coming away, it is focused by concave mirror **CM** to photomultiplier **PM**.

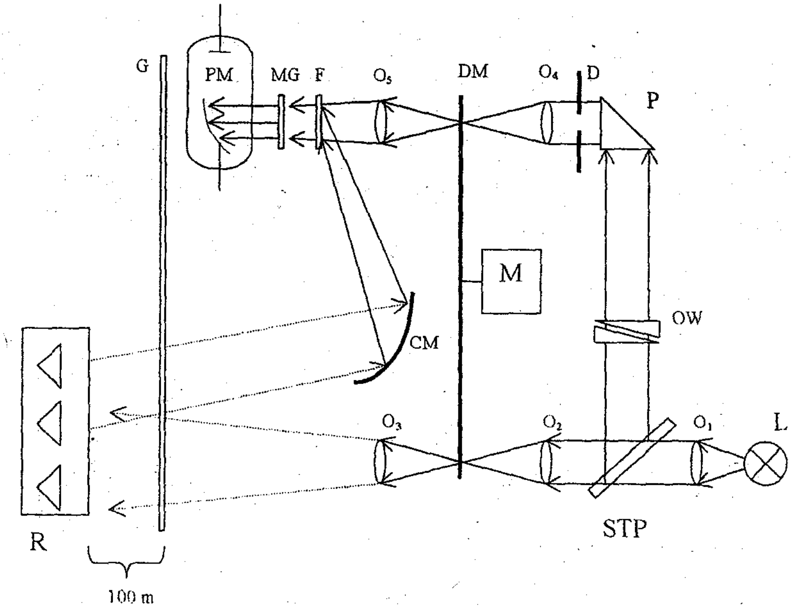

Fig. 19.1. Optical system of РДВ-3.

The comparative beam passes through optical wedges **OW**. The observer may regulate the comparative beam luminance with these optical wedges. Then the beam is turned to 90^0 by the prism **P** and passes through measure diaphragm **D**. This diaphragm is operated with the reverse motor **RM** and reduction gear **RG** (see fig. 19.3). Then the comparative beam passes through upper edge of disk-modulator and goes to photomultiplier **PM**.

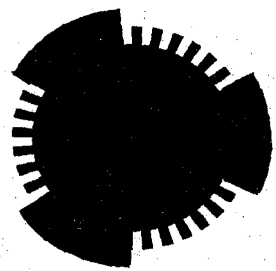

Fig. 19.2. Disk-modulator.

The comparative beam, as the sounding beam passes through light filter **F** and mat glass **MG**. The light filter makes the light spectrum be equal to spectral sensitivity of man's eye. The mat glass is to disperse the light to all the surface of photocathode.

The photomultiplier converts the optical signal to electric signal. But to understand the electric signal transformations we need another diagram - see the block-diagram pictured on fig.19.3.

Now we'll study this block-diagram. To make it clear we'll draw voltage patterns at marked parts of the block-diagram. These voltage patterns are drawn on fig.19.4. When optical signal comes to photomultiplier PM (fig.19.3.) it is the same, as fig.19.4.a shows. Let sounding beam be more than comparative beam - for example, a fog is evaporated. Let's prove it causes the equalization of these beams.

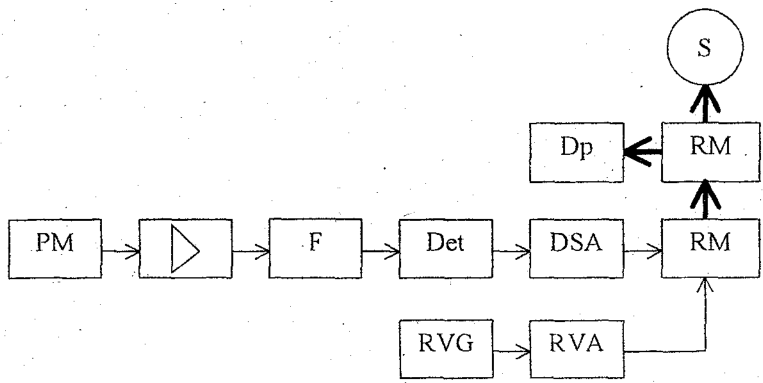

Fig. 19.3. The block-diagram of РДВ-3.

Photomultiplier converts the signal to electric form. Being amplified it has the form, shown on fig.19.4.b. This form is due to special electric circuit, used for the amplifier. Such a signal goes to detector (Det). We have an envelope, it goes to filter F (fig.19.3.). The filter makes the periodic sinusoidal signal (fig.19.4.c.). Of course, this sinusoidal signal exists when sounding and comparative beams aren't equal. That's why this signal is named the *disbalance signal*. Being amplified by disbalance signal amplifier (DSA, fig.19.3.) it goes to reverse motor RM (fig.19.3.).

Another signal is generated by reference signal generator (RVG). This signal is named *reference signal*, it is shown on fig.19.4.d. It has the same frequency as the disbalance signal, but it is shifted to 90^0 (compare curves "c" and "d" on fig.19.4.). If both signals go to reverse motor, the RM rotates. And it moves the diaphragm D (see fig.19.3. and 19.1.) by the reduction gear RG. If the comparative beam is less then the sounding, the reduction gear opens the diaphragm.

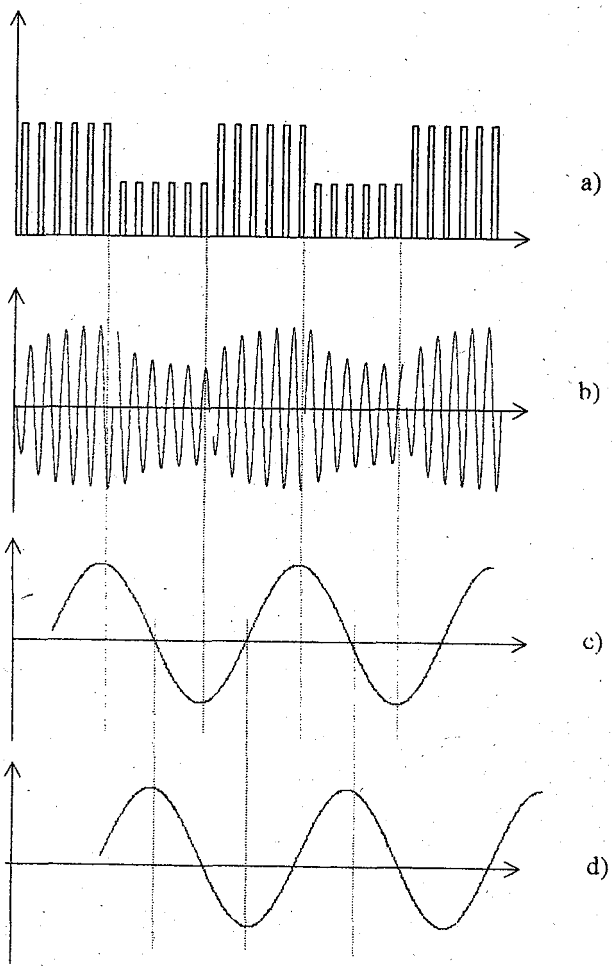

Fig.19.4. Voltage patterns.

The comparative beam increases and when the amplitudes of beams become equal, the disbalance signal becomes zero. On the other hand, the scale rotates too, and when disbalance signal disappears, it stops. The position of the scale shows the value of MVR.

If the weather situation is such that comparative beam is more than the sounding, the disbalance signal changes the phase to 180^0 . Then the phase shift of disbalance signal and reference signal is -90^0 and the reverse motor rotates to another direction. The diaphragm closes and comparative signal decreases. The scale rotates to another direction too.

It's very easy to operate with РДВ-3. But it cannot measure the MVR less than 200 m., because the luminance of the reflected sounding beam, is very low. That's why РДВ-3 was changed by ФИ-1 – it is more perfection device than РДВ-3.

VOCABULARY

transparency - прозрачность
transmissometer - трансмиссометр (название употребляется преимущественно в англоязычной литературе)
sounding beam - зондирующий луч
diaphragm - диафрагма
comparative beam - луч сравнения
automatic recorder - самописец
mat glass - матовое стекло
light filter - светофильтр
concave - вогнутый
disk-modulator - диск-модулятор
reduction gear - редуктор (зубчатая передача для уменьшения скорости вращения)
optical wedge - оптический клин
prism - призма
semitransparent plate - полупрозрачная пластина
pattern - эпюра (графическая зависимость от времени какой-либо величины, обычно - электрической)
equalisation - выравнивание
envelope - (здесь) огибающая
perfection -совершенный

Lecture 20.

PULSE PHOTOMETER ФИ-1.

Pulse photometer ФИ-1 is the transmissometer, as well as РДВ-3. But the range of ФИ-1 is from 50m to 6000m. So, you see, it can be used for MVR measurements even when a fog is very dense. How can it be achieved? Two ways for it are used.

1. The luminance of light source in ФИ-1 is much more, than in РДВ-3. It is the pulse gas lamp.

2. There are two reflectors to be used in ФИ-1. One of them, the distant reflector (DR) is placed at 100m distance from photometer block. Another, the near reflector (NR) is placed at 20m distance. It is used when MVD is less then 400m.

The principle of operation of ФИ-1 is another, than of РДВ-3. The comparative beam isn't regulated here. And the optical system of ФИ-1 is simpler. You can see it on fig.20.1.

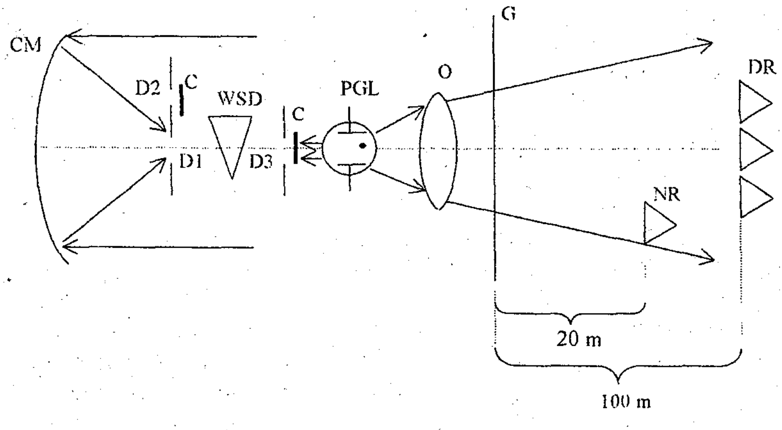

Fig.20.1. Optical diagram of ФИ-1.

The *pulse gas lamp* PGL gives light pulses, their frequency is 50 Hz. The sounding beam goes through the *objective* O and through the *glass* G to atmosphere. There are two reflectors – *distant reflector* DR and *near reflector* NR, irradiated by the beam. But DR is placed on the optical axis of the photometer, and NR is displaced down from the axis. Due to it the beam reflected by DR goes to the *concave mirror* CM and then through the *diaphragm* D1, placed on the optical axis too. As to the beam, reflected by NR, it goes through the *diaphragm* D2; this diaphragm is displaced up from the axis. To use NR or DR it's enough to close one of the diaphragms - D1 or D2. It can be done with the *optical commutator* C. After the diaphragm (D1 or D2) the sounding beam goes to the *wedge-shaped diffuser* WSD. It is a white wedge, scattering the light beams to a photomultiplier (it isn't shown on fig.20.1). Speaking about the comparative beam, we see - it goes through the diaphragm D3 to the spherical diffuser SD. The diaphragm D1 and D3 (or D2 and D3) are closed in turns. The frequency of this close-open process is 1 Hz. We'll call it *commutation frequency*.

Now we'll consider the block-diagram of pulse photometer ФИ-1. It is drawn on fig.20.2. To understand the operating of this diagram we'll draw the voltage patterns at different points of this block-diagram. These voltage patterns are drawn on fig.20.3.

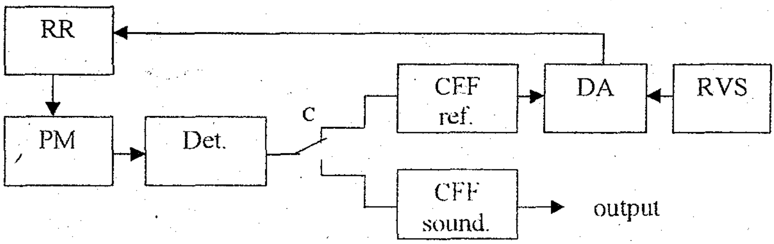

Fig.20.2. The block-diagram of ФИ-1.

The light signal, coming to *photomultiplier* PM, is drawn on fig.20.3.a. (Suppose, comparative beam is more than sounding beam).. Photomultiplier converts this signal to electric form, so the output signal of PM has the same form, as shown on fig. 20.3.a. This signal comes to *detector* (Det). The detector converts it to right-angle pulses (see fig.20.3.b.). The amplitude of these pulses depends upon the luminance of light signals.

These pulses are divided by *commutator* C - the pulses from comparative signal come to *commutation frequency filter* of comparative signal (CFF comp.); the pulses from sounding signal come to CFF of sounding signal (fig. 20.3.c.). This electrical – commutator C operates with the same rate as optical commutator that is drawn on fig. 20.1. The commutator frequency filter is a detector having a high time constant.

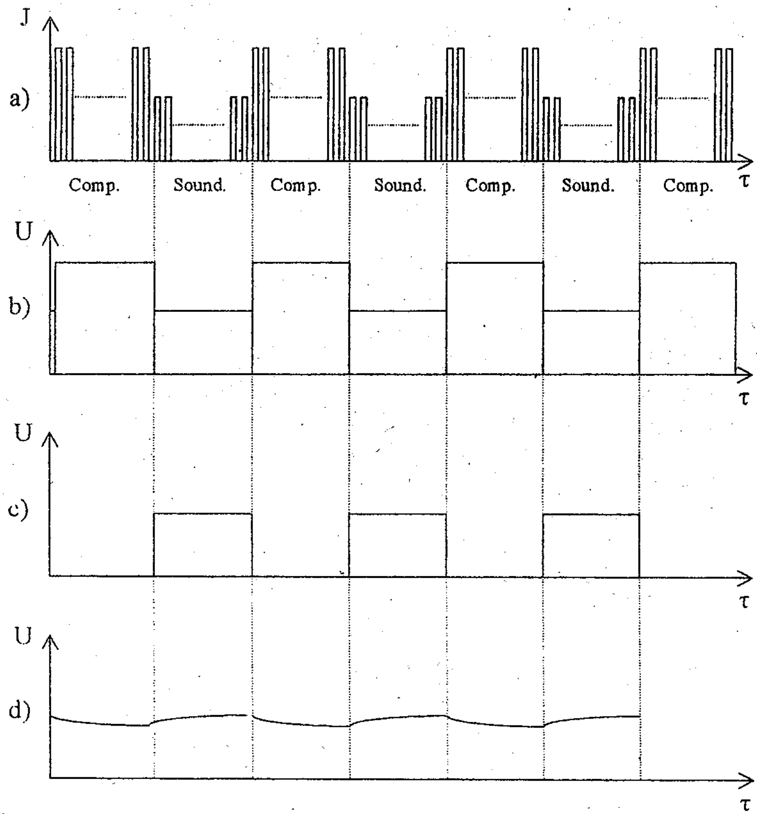

Fig.20.3. Voltage patterns for ФИ-1.

Therefore the output signal of CFF is rather constant voltage (fig.20.3.d.). The output voltage from CFF of sounding signal depends on two parameters - the MVR (of course!) and a lamp luminance (that's a pity!). To make this voltage only one parameter's function there is another channel. The output voltage from CFF of comparative signal depends only upon the lamp luminance. It comes to the first input of the *differential amplifier* (DA). Constant voltage (40v) comes from reference voltage source (RVS) to the second input of DA. Comparing these two voltages DA sends the signal to *regulated rectifier* (RR). RR increases or decreases the anode voltage of photomultiplier PM.

For example, let the lamp luminance be more than usual. Then the voltage signal from CFF of comparative signal is high. It is more than 40v from RVS. Then DA gives a command signal to RR - to reduce the anode voltage! The anode voltage reduces, the sensitivity of photomultiplier PM reduces, and all the signals on fig.20.3 (b, c and d) reduce too. As a result, the voltage from CFF of comparative signal is always equal to 40v, and the voltage from CFF of sounding signal doesn't depend on lamp luminance. Now it depends only from MVR. To linearise this dependence and to convert the signal to digital from there is one more block – *the functional converter*. It forms the controlling signals to change NR to DR or DR to NR.

VOCABULARY

Dense – густой, плотный
Pulse gas lamp – импульсная газоразрядная лампа
Wedge-shaped diffuser – клинообразный рассеиватель
Differential amplifier – дифференциальный усилитель
Reference voltage source – источник опорного напряжения

Lecture 21.

RADIOACTIVITY MEASUREMENTS.

Before speaking about radioactivity measurements themselves I'd like to say a few words about units of radioactivity values.

Radioactive emission appears when nuclei decay. The radioactive emission irradiates a substance causing changes of its state. Therefore there are several values of radioactive emission. Some of them define a radioactive substance itself, but another defines changes of irradiated substance. Let's list them all.

1. ***Radioactivity*** (**A**). It is a number of nuclei decaying per one second. Of course, radioactivity **A** depends on radioactive substance nature and on the amount of this substance. It can be measured in backerels [Bq]:

$$1\ \mathrm{Bq} = 1\ \mathrm{s}^{-1}.$$

It is SI-unit. But it is very low to use it in practice. Usually we use another value, 1 Curio. It is equal to radioactivity of 1 gram of radium. We can write the relation:

$$1\ \mathrm{Cu} = 3.7 \cdot 10^{10}\ \mathrm{Bq}.$$

When we investigate the radioactive pollution of a place, such value as curio per kilometer a square can be used (Cu/km^2).

2. ***Absorbed dose*** (**D**) is the ratio of the energy (**W**), absorbed by irradiated body (or a substance) to a mass of this body (**m**):

$$D = W / m.$$

Of course, it can be measured in Joules per kilogram. Such a unit is called 1 Gray (1 Gy):

$$1\ \mathrm{Gy} = 1\ \mathrm{J} / \mathrm{kg}.$$

But this value is too high for using in practice. Another unit is called 1 rad (1 rad):

$$1\ \mathrm{rad} = 10^{2}\ \mathrm{Gy} = 10^{2}\ \mathrm{J} / \mathrm{kg}.$$

When we speak about possible exposition to radiation, we use such a unit as rad per year (per hour, per second).

3. ***Exposive dose*** (**I**) - it is a ratio of the charge (**Q**), appearing within dry air due to radiation to mass of this air (**m**). It can be measured in culones per kilogram, or in roentgen (1 R):

$$1\ R = 2.58 \cdot 10^{-4}\ C/Kg.$$

The following relationships can be obtained:

$$1\ R = 8.77 \cdot 10^{-3}\ Gy$$
$$1\ R = 0.877\ rad; \quad 1\ rad = 1{,}14\ R.$$

Usually we use such a unit as roentgen per hour (or microroentgen per hour).

4. ***Dose power*** (D^{*}) is a ratio of a dose, absorbed by body, to absorption time (τ):

$$D^{*} = D / \tau$$

The following equation can be obtained:

$$D^{*} = \frac{K \cdot A}{r}$$

where r is a distance between the radioactive substance and a body, irradiated by it; K is the coefficient for this substance. Table (tab.21.1) gives this coefficient:

Tab.21.1

Substance	Co_{60}	J_{131}	Cs_{237}	U_{238}
K ($J \cdot m^2/kg$)	$1 \cdot 10^{-16}$	$1{,}71 \cdot 10^{-17}$	$6{,}8 \cdot 10^{-17}$	$6{,}81 \cdot 10^{-19}$

When a place is investigated in relation to radioactive pollution the distance r (the altitude above the ground) is adopted as 1,5 m. Then:

$$D^{*} = \frac{K \cdot A}{2{,}5}$$

But the most important for man is the reaction of man's body to radioactive emission. Therefore the fifth unit is given.

5.***Equivalent dose*** (D_e) is an absorbed dose D, multiplied by coefficient (Q). It is named 1 ber (biological equivalent of roentgen):

$$D_e = Q \cdot D$$

The coefficient Q depends on radiation nature. You can found it in table 21.2.

Tab.21.2.

Type of radiation	X-rays, γ-rays, β-rays	α-rays, rapid neutrons	Broken nuclei
Q (ber/rad)	1	10	20

As you see, broken nuclei are most dangerous for men.

Now a few words about norms of radioactive emission for men. They are different. The thing is that people are divided by three groups in relation to radioactivity. These groups are following.

1. Specialists - people, working with radioactive substances.
2. People, working with radioactive substances from time to time.
3. Other population.

Specialists are controlled by physicians and the norms for them are highest. Table 21.3 gives safe values of most important parameters of radioactivity. The nature radioactive background is given here too.

Tab.21.3

Group of population	A, Cu/km	$D^{\cdot}$, μR/h	D_e, ber/year
1	100	32500	5
2	10 - 20	3250	0,5
3	1 -2	325	0,05
Nature background	0,1 ÷ 0,02	10 ÷ 20	~ 0,002

The nature radioactive background varies from region to region, from one place to another. It is highest at mountains. But if $D^{\cdot}$ is more than 60 μR/h, meteorologist must inform authority organs about it.

Now let's speak about radioactivity measurements themselves.
We'll study 3 methods. They are following.

1. Geiger counters.
2. Proportional counters.
3. Scintillation counters.

Geiger counter was invented in the first part of this century. The main part of this counter is the gas-filled tube (fig.21.1.) with two electrodes - anode (1) and cathode (2).

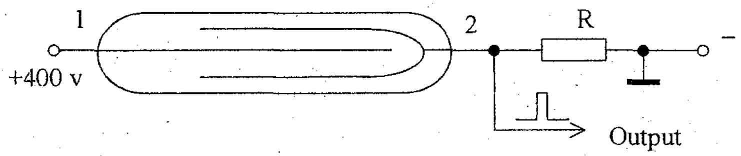

Fig.21.1.

The gas pressure within the tube is low. When a radioactive particle flies to the tube, it can ionize one of atoms. Charged particles (ions) fly to anode or to cathode and ionize one more atom. And so on, the chain reaction begins and all the atoms within the tube become ionized. The resistance of the tube (R_t) decreases. The tube flashes. But there is a resistance R connected with the tube in series. The value R is about $10^6 \div 10^7$ ohms. When the tube is off, $R_t >> R$, and there is a high voltage between anode and cathode, $U_{ac} \sim 400v$. But when the tube flashes, $R_t << R$, and $U_{ac} \sim 0$. The chain-reaction finishes and the tube becomes quenched. But the voltage pulse appears on the output. It is clear, the frequency of these pulses is the measure of radioactivity. It can be measured with frequency counter.

Proportional counters have the same tube, but the voltage U_{ac} there is not so high, and the gas pressure within the tube is less. Due to it a chain-reaction doesn't occur and ions move to electrodes without collisions. Thus, there is a faint current through the tube. It is proportional to radioactive emission and can be measured with instrument.

Scintillation counters. The main part of these devices is a bit of substance that emits a visible light being exposed by radiation. When radioactive particles fly through the substance, a light pulse appears. These light pulses are converted to electric pulses (with a photomultiplier). Then the frequency of pulses has to be measured with frequency counter. Such counters are most sensitive.

A very interesting digital counter will be given here some later, when we'll study digital elements.

VOCABULARY

Decay – распадаться (например, о ядрах атомов)
Backerel – беккерель
Radium – радий
Curio – кюри
Absorbed dose – поглощенная доза
Gray – грей
Rad – рад
Exposive dose – экспозиционная доза
Roentgen – рентген
Dose power – мощность дозы
Equivalent dose – эквивалентная доза
Nature radioactive background – естественный радиационный фон
Authority organs – органы власти
Geiger counter – счетчик Гейгера
Scintillation – сцинтилляция
Chain reaction – цепная реакция
Flash – вспыхивать
Quench – гаснуть
Faint – слабый

Lecture 22.

DIGITAL MEASURING DEVICES

All the previous lectures we were speaking about devices with a scale instrument. There an angle of a pointer is proportional to measuring parameter. Such devices are named *analog devices*. But *digital devices* haven't got a scale, they have digital indicator – with a light elements, for example. These elements may be on or off. Thus an output signal has only two possible values - zero (or low level signal) and high level signal (more than zero). We'll call such a values - 0 and 1. And there are many wires for this signal - a wire to each light element. When there is a voltage on a wire (or signal is equal to 1), light element is on, when there isn't voltage (signal is equal to 0), light element is off.

Such signals are named *digital signals*. Now we'll study the forming of digital signal as a function of meteorological parameters.

DIGITAL CODES

First of all we'll notice the following. Any physical parameter can be characterized by a number. To write a number we usually use the decimal system. It can be described with ten signs, or *digits* (from 0 to 9) and some *orders*. Let's denote the value of a digit as a_i, where **i** is an order's number. Then a value A can be expressed by formula:

$$A = a_1 \cdot 10^{n-1} + a_2 \cdot 10^{n-2} + \cdots + a_{n-1} \cdot 10^1 + a_n \cdot 10^0 \qquad (22.1)$$

For example, the number 2003 can be expressed:

$$2003 = 2 \cdot 10^3 + 0 \cdot 10^2 + 0 \cdot 10^1 + 3 \cdot 10^0$$

Decimal system is very convenient to use it for writing and operating. But is it suitable to use it for electronic signals? Of course, no. It would be necessary to use ten voltage levels. To generate and to analyze such a signal we would have complex circuits. And why decimal system is used now? Long time ago men counted with fingers, that's why. We may use any system, it doesn't matter.

Let's chouse a binary system. It's very easy to generate a binary electronic signal (a voltage is being or not!). Using such a system we can express a value A by formula:

$$A = a_1 \cdot 2^{n-1} + a_2 \cdot 2^{n-2} + \cdots + a_{n-1} \cdot 2^1 + a_n \cdot 2^0 \qquad (22.2)$$

where a_i can have two levels - 0 or 1. For example, the number 5 can be expressed:

$$5 = 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0$$

All the mathematics operations can be done by using the decimal system. The same can be done by binary system. Binary system is used in all electronic digital devices (computers, calculators and so on).

GATES (SIMPLE INTEGRAL CIRCUITS).

Simple integral circuits (*gates*) make only one simple operation. There are only three of them - "**AND**", "**OR**" and "**NO**".

The gate **AND** has two inputs: $\mathbf{x_1}$ and $\mathbf{x_2}$ and one output **y**. Of course, there must be digital signal at inputs and at output. Let's express the possible signals by table 22.1.

We desire - **y** = 1 only when $\mathbf{x_1}$ = 1 and $\mathbf{x_2}$ =1! Any other combination of input signals corresponds to **y** = 0.

Tab.22.1

x_1	x_2	y
0	0	0
0	1	0
1	0	0
1	1	1

You see, output signal **y** may be expressed by product:

$$\mathbf{y = x_1\ x_2}$$

That's why the operation, made by this gate is called *logic multiplication.*

This gate may be constructed with two n-p-n transistors, connected in series (fig.22.1.):

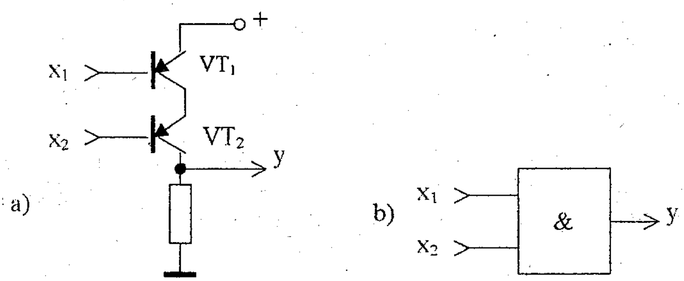

Fig.22.1. The gate **AND** (a) and its logic symbol (b).

A positive voltage is there at output **y** only when both VT_1 and VT_2 are turned on. It means, $\mathbf{x_1} = 1$ and $\mathbf{x_2} = 1$.

The gate **OR** has two inputs and one output, as well as the gate **AND**. But the table for it is following (tab.22.2):

Tab.22.2.

x_1	x_2	y
0	0	0
0	1	1
1	0	1
1	1	1

Output signal y is equal to 1 when $\mathbf{x_1} = 1$ *or* $\mathbf{x_2} = 1$! Pay attention - output signal **y** can be represented as a sum of $\mathbf{x_1}$ and $\mathbf{x_2}$ taking into account the rule: 1 + 1 = 1. It is so indeed at logic algebra. Thus:

$$\mathbf{y = x_1 + x_2}$$

This operation is called *logic addition.*

As well as the previous, the gate **OR** may be constructed with two n-p-n transistor. But they must be connected in parallel (fig.22.2).

A positive voltage can be at the output y when VT_1 or VT_2 are turned on (or both VT_1 and VT_2).

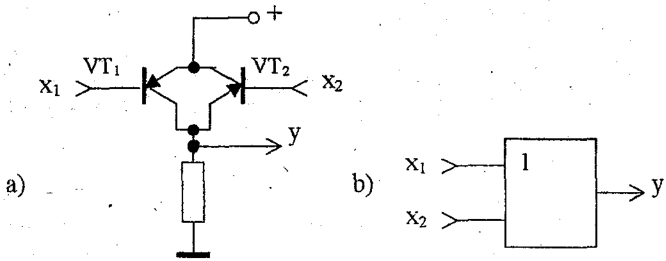

Fig.22.2. The gate **OR** (a) and its logic symbol (b).

The last gate **NOT** has only one input **x** and one output **y**. The table for its state is the following (tab.22.3):

Tab.22.3.

x	**y**
0	1
1	0

Here output signal has the opposite value with the input signal. That's why this operation is called *logic inversion* and can be written by formula:

$$y = \overline{x}$$

This operation hasn't analog in usual algebra.
Such a gate can be constructed with only one n-p-n transistor (fig.22.3).

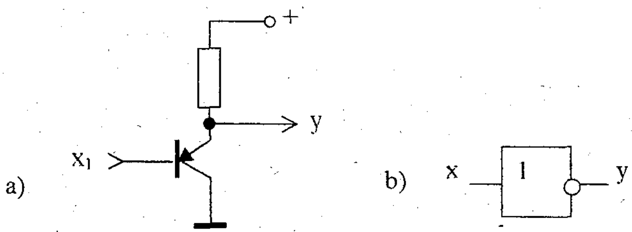

Fig. 22.3. The gate **NO** (a) and its logic symbol (b).

It is clear - output y has a positive voltage when transistor is turned off by zero signal at the base (**x** = 0).

LOGIC ALGEBRA FOUNDATIONS.

Logic algebra or Boolean algebra operates with binary variables. Each variable can have only two levels - 0 or 1. Logic algebra has its own laws. We've mentioned one of these laws:

$$1 + 1 = 1.$$

How can we understand it? Suppose, you are going to go to the theatre. You thing: *"I'll go to the theatre if I bye the ticket, or my friend invite me"*. There are three logic variables in this sentence:

T (theatre) - T = 1 (I'll visit a theatre)
T = 0 (I'll not visit it)
t (ticket) - t = 1 (I'll bye the ticket)
t = 0 (I'll not bye it)
i (invitation) - i = 1 (I'll be invited)
i = 0 (I'll not be invited)

Then T can be expressed with formula:

$$T = t + i$$

Suppose, t = 1 (you've bought the ticket) and i = 1 (your friend invites you). Do you agree with me, T = 1? Thus, 1 + 1 = 1 indeed!

There are many other roles at logic algebra. Some of them are written here :

$$x + 0 = x \qquad x \cdot 0 = 0$$
$$x + 1 = 1 \qquad x \cdot 1 = x$$
$$x + x = x \qquad x \cdot x = x$$
$$x + \overline{x} = 1 \qquad x \cdot \overline{x} = 0$$

Think about these roles. They are clear.

Let's make a short exercise with these roles. For example, the following sentence: *"I'll go to the theatre (T) if I bye the ticket (t), or my friend invite me (i); and if the expedition (e) will not take a place."* Let's write it by formula:

$$T = (t + i) \cdot \overline{e}$$

It was very easily to write this formula. It was enough to read the sentence attentively to do it. Let's do the more difficult exercise. Suppose, we want to construct a device for voting. There are only three persons to vote. Each of them presses the button if he vote "for" and doesn't press it voting "against". Let's denote the opinion of each person as $\mathbf{x_i}$ ($\mathbf{x_1}$; $\mathbf{x_2}$; $\mathbf{x_3}$). And there is a lamp (**y**), it is switched on when a project is passing on.

We cannot write a formula for **y** immediately. But the following table (tab.22.4.) can be written.

Tab.22.4.

x_1	x_2	x_3	y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Now let's look at this table attentively. We'll notice:
"$\mathbf{y} = 1$ if $\mathbf{x_1} \neq 1$ and $\mathbf{x_2} = 1$ and $\mathbf{x_3} = 1$; or $\mathbf{x_1} = 1$ and $\mathbf{x_2} \neq 1$ and $\mathbf{x_3} = 1$; or $\mathbf{x_1} = 1$ and $\mathbf{x_2} = 1$ and $\mathbf{x_3} \neq 1$; or $\mathbf{x_1} = 1$ and $\mathbf{x_2} = 1$ and $\mathbf{x_3} = 1$".
Now we can write the formula:

$$y = \overline{x_1} \cdot x_2 \cdot x_3 + x_1 \cdot \overline{x_2} \cdot x_3 + x_1 \cdot x_2 \cdot \overline{x_3} + x_1 \cdot x_2 \cdot x_3$$

Of course, we might construct the electronic circuit, using this formula. It would be taken: eight gates **AND**, three gates **OR** and three gates **NO**. Can we simplify this expression? Let's try. Taking into account the rule x + x = x , we may add two terms ($\mathbf{x_1 \cdot x_2 \cdot x_3}$) and group terms together:

$$y = (\overline{x_1} \cdot x_2 \cdot x_3 + x_1 \cdot x_2 \cdot x_3) + (x_1 \cdot \overline{x_2} \cdot x_3 + x_1 \cdot x_2 \cdot x_3) + (x_1 \cdot x_2 \cdot \overline{x_3} + x_1 \cdot x_2 \cdot x_3)$$

Let's factor some variables out of brackets:

$$y = x_2 \cdot x_3 \cdot (\overline{x_1} + x_1) + x_1 \cdot x_3 \cdot (\overline{x_2} + x_2) + x_1 \cdot x_2 \cdot (\overline{x_3} + x_3)$$

But taking into account the rule:

$$x+\bar{x}=1$$

we can write:

$$y = x_2 \cdot x_3 + x_1 \cdot x_3 + x_1 \cdot x_2 = x_3 \cdot (x_2 + x_1) + x_1 \cdot x_2$$

To construct the circuit using this expression we'd need only two gates **AND** and two gates **OR** (fig.22.4):

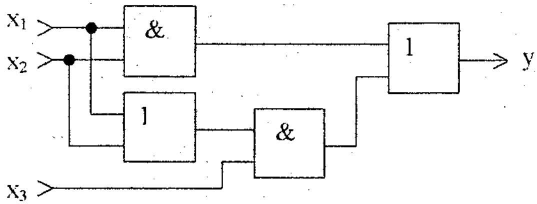

Fig. 22.4. The electronic circuit for voting.

Now let's write a rule (algorithm) for electronic circuits construction. Suppose, there are k inputs and n outputs in it. To construct the circuit we must:

1. Write tables for each output **y**.
2. Write expression for every **y**. To do so we'll take all lines where **y** = 1 and write the sum of products of all **x** (if **x** = 1, **x** must be taken).
3. Simplify this expression.
4. Construct electronic circuit.

Using this algorithm, any complex circuit can be constructed! One more example. Let's write a table for seven-element indicator control. Such a circuit must have seven outputs (see fig.22.5).

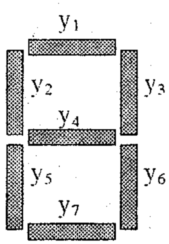

Fig.22.5. Seven-element indicator.

Suppose, a digital signal comes to inputs. And the indicator must show a usual number. For example, when input value is 1 (0001), $\mathbf{y_2}$ and $\mathbf{y_5}$ must be switched on, other elements - be off. Other signals are shown in the table 22.5.

Of course, the circuit made according this table would be complex. Fortunately, such circuits are already constructed. Now we can use them to construct more complex circuits.

Tab.22.5

Indicated number	Input signals				Output signals						
	x_1	x_2	x_3	x_4	y_1	y_2	y_3	y_4	y_5	y_6	y_7
1	0	0	0	1	0	0	1	0	0	1	0
2	0	0	1	0	1	0	1	1	1	0	1
3	0	0	1	1	1	0	1	1	0	1	1
4	0	1	0	0	0	1	1	1	0	1	0
5	0	1	0	0	1	1	0	1	0	1	1
6	0	1	1	0	1	1	0	1	1	1	1
7	0	1	1	1	1	0	1	0	0	1	0
8	1	0	0	0	1	1	1	1	1	1	1
9	1	0	0	1	1	1	1	1	0	1	1
0	0	0	0	0	1	1	1	0	1	1	1

VOCABULARY

Digital - цифровой
Decimal system – десятичная система
Binary system – двоичная система
Gate – логический элемент, малая интегральная схема
Boolean algebra – булева алгёбра
Voting - голосование

Lecture 23.

MEDIUM SCALE INTEGRATION CIRCUITS (MSI)

Last lecture we've spoken about gates. We learned the algorithm for construction any circuit, using gates **AND**, **OR** and **NO**. But it would be very difficult to use this algorithm every time. It's more convenient to use such a way only once, using complex circuit as a result next time. Such circuits are constructed. They are named *medium scale integration circuits (MSI)* and *high integration circuits* (HIC). We'll mention only some of MSI.

1. **Code converter**. These circuits are used to convert signals from one code to another. For example, last lecture we wrote the table for one of them. It converts the digital code to code for seven-element indicator. Another code converters may be represented. They all have the symbol, pictured on fig.23.1.

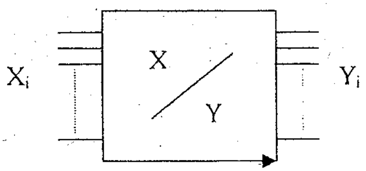

Fig.23.1. Code converter

There are n inputs and k outputs. Such converters are constructed according the algorithm, we've spoken last lecture.

2. **Counters**. Counter solves the problem - to count pulses coming from a circuit or from a device. The answer must be done in digital code. Counter is the circuit with flip-flops, connected in series (fig.23.2.)

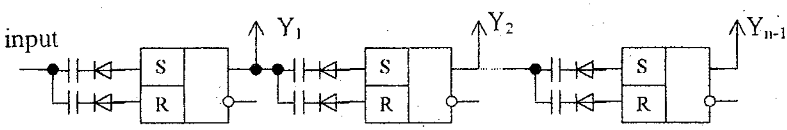

Fig.23.2. Counter.

These flip-flops are made with n-p-n transistors. Such a flip-flop *sets* when the negative pulse comes to S-input. It *resets* when negative pulse passes to R-input. Diode-capacitor circuit converts a right-angle pulse to momentary negative pulse (see fig.17.9). Thus the first pulse causes the first flip-flop being sets. A voltage appears at Y_1 ($Y_1 = 1$). But the second flip-flop doesn't change its state because of the diode direction. The second pulse causes the first flip-flop being resets (the R-input operates!). The voltage on Y_1 falls down ($Y_1 = 0$), but it causes the second flip-flop being sets and the voltage at Y_2 appears. The output signals are given in table 23.1.

Tab.23.1.

Input pulse number	Output signals			
	Y_1	Y_2	Y_3	Y_4
$0 = 0 \cdot 2^0 + 0 \cdot 2^1 + 0 \cdot 2^2$	0	0	0	0
$1 = 1 \cdot 2^0 + 0 \cdot 2^1 + 0 \cdot 2^2$	1	0	0	0
$2 = 0 \cdot 2^0 + 1 \cdot 2^1 + 0 \cdot 2^2$	0	1	0	0
$3 = 1 \cdot 2^0 + 1 \cdot 2^1 + 0 \cdot 2^2$	1	1	0	0
$4 = 0 \cdot 2^0 + 0 \cdot 2^1 + 1 \cdot 2^2$	0	0	1	0
$5 = 1 \cdot 2^0 + 0 \cdot 2^1 + 1 \cdot 2^2$	1	0	1	0

Looking at the table we see - the whole output signal (Y_1, Y_2, ...) is a number of input pulse in digital code! The highest digit is y_{n-1}, the low-digit is Y_1.

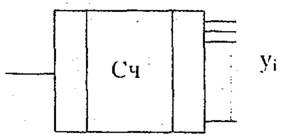

Fig.23.3. Counter (logic symbol).

Such a counter is there in modern M-63M-1, we've mentioned some times ago. Fig.23.3. shows a logic symbol of a counter.

3. **Comparator**. Comparator solves a problem to compare two voltage values. This circuit has two inputs. Analog signals (voltages U1 and U2) come to these inputs. One output - y - gives a digital signal. If $U1 < U2$ then $y = 0$; if $U1 > U2$ then $y = 1$. Logic symbol of comparator is drawn on fig.23.4. Many electronic circuits of comparators can be imagined. We'll not discuss them now. Many others MIC can be mentioned. They are described in special literature.

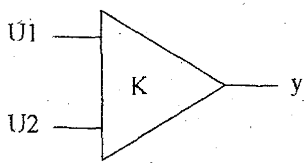

Fig.23.4. Comparator.

DIGITAL - ANALOG CONVERTERS

To convert analog signal to the digital form or digital signal to analog form analog-digital converters (ADC) or digital-analog converters (DAC) are used. Let's consider the digital-analog converters (DAC).

So, the digital signal has to be converted to analog form - current, for example. Let's remember the formula for a digital signal:

$$A = a_1 \cdot 2^{n-1} + a_2 \cdot 2^{n-2} + \cdots + a_{n-1} \cdot 2^1 + a_n \cdot 2^0 \qquad (23.1)$$

where $a_i = 0$ or $a_i = 1$.

The value A is a sum of **n** terms, where **n** is the number of digits; the low-digit ($a_n \cdot 2^0$) is a least term, the highest is digit ($a_1 \cdot 2^{n-1}$). But coefficient a_i may be equal to 1 or to zero. This, to convert a digital signal to analog form two problems must be solved.

1. To establish a circuit, giving the opportunity to obtain current output signals I_i so, that $I_i = 2 \cdot I_{i-1}$.
2. To connect outputs of this circuit with a special circuit to sum currents. An output must be connected with a key; a key must be on if $a_i = 1$, or be off if $a_i = 0$.

Electronic keys can solve the second problem. Such a key uses a n-p-n transistor, it is on if a positive voltage (logic 1) is at the base, it is off when the base has zero voltage. Thus, such a key can be controlled with a voltage at input a_i. You can see electronic key's symbol on fig.23.5. The wire x is connected with the wire y when a=1 only.

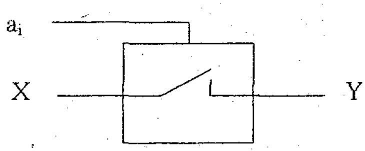

Fig. 23.5. Electronic key.

Now let's consider the DAC-circuit as a whole (fig.23.6.)

A reference voltage U is used to form a current output signal. Input a_i have a digital signal ($a_i = 0$ or $a_i = 1$).

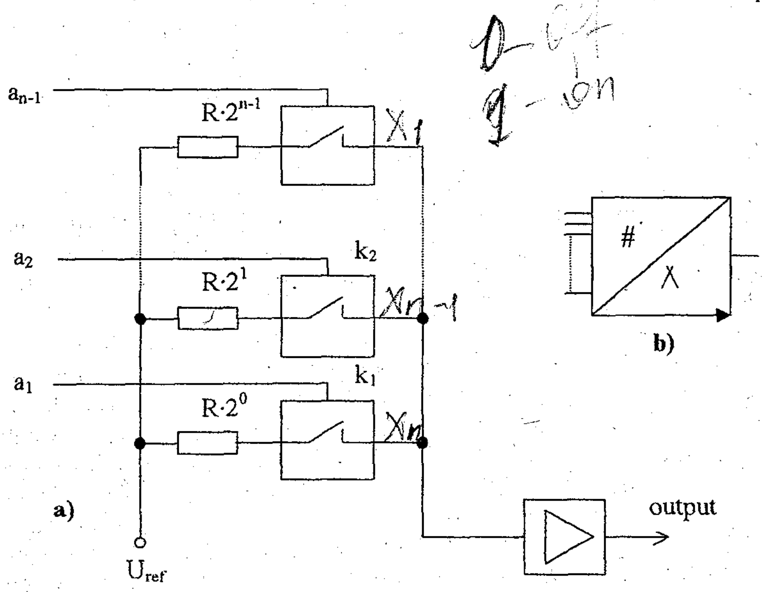

Fig.23.6. DAC-circuit (a) and its logic symbol (b).

Thus, electronic keys k_i may be on or off. The currents that go through resistors can pass through a key or not, according to a_i. But the next resistor's value is two times more than previous. Thus, the current though k_i is two times less than the current through k_{i-1}. Currents from electronic keys outputs are added according to Kirchhoff's law. The total current passes to amplifier. And we get an analog signal at the output of amplifier (according to formula 23.1).

Of course, DAC cannot represent a digital signal more precisely than low-digit weight. But it cannot be otherwise!

This DAC uses a big number (n) of resistance values. It's a shortcoming of this circuit. Another circuits may be used to avoid this difficult. They are described in special literature.

VOCABULARY

Medium scale integration circuits (MSI) – средние интегральные схемы (СИС)
High integration circuits (HIC) – большие интегральные схемы (БИС)
Code converter – преобразователь кодов
Counter – счетчик
Comparator – компаратор

Lecture 24.

ANALOG - DIGITAL CONVERTERS.

Analog-digital converter (ADC) solves the problem to convert analog signal to digital form. This conversion cannot be made more precisely than low-digit weight. We understand, it cannot be otherwise. To convert more precisely a number of digits must be increased.

How can the problem of conversion be solved? To understand it let's compare an ADC with a cap balance. To weigh a body we must put this body's weight in equilibrium with balance weights on another cup. Of course, it cannot be done more precisely than a lowest balance weight. So, let's put the body to a cup and one smallest balance weight to another cup. If the body's weight is more than balance weight, let's add one lowest weight more. And so on, let's add and compare. Let somebody to count our balance weights. When balance weight will more (or equal) than body's weight, let's stop the process. A number of balance weights will be equal to body's weight.

To carry such an algorithm the circuit, drawn on fig.24.1 can be used.

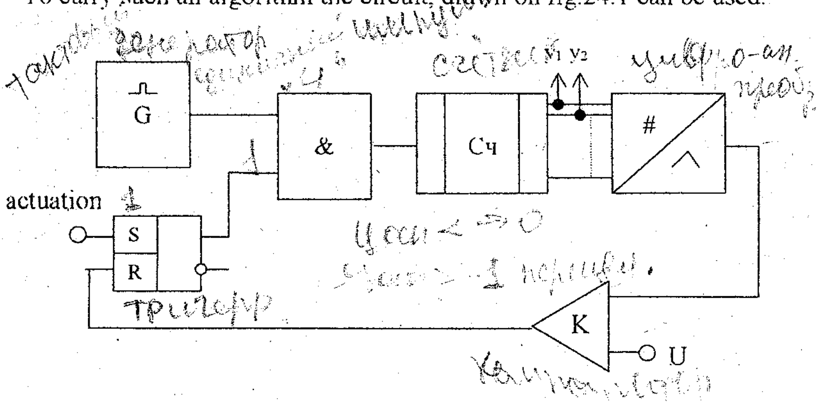

Fig.24.1. Analog-digital converter (ADC).

Generator **G** produces right-angle pulses. They play the role of lowest weight. To drive this circuit a voltage (logic "1") must be given to input "actuation". It's a flip-flop's s-input. The flip-flop sets and the voltage ("1") goes to the lower input of the gate AND. Since this moment pulses from generator pass through gate AND to the counter **Сч**. It counts these pulses and a number (in digital code) appears at outputs. This number increases from pulse to pulse. Digital-analog converter converts this number to voltage U_{DAC} . This voltage increases too. Comparator **K** compares this voltage U_{DAC} with an input voltage U. If $U_{DAC} < U$, there is "0" at comparator's output. But U_{DAC} increases; as soon as U_{DAC} becomes a bit more then U, logic "1" appears at the output of comparator. It comes to R-input of the flip-flop and the flip-flop resets. The logic "0" appears at the lower input of gate AND. Since this moment pulses from generator cannot pass through the gate AND and the number at outputs becomes constant. It's easily to understand - this number is equal to output voltage U in digital code!

ADC - logic symbol is drawn of fig.24.2.

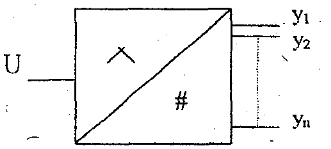

Fig.24.2. Logic symbol of DAC.

You see, the conversion can be done more quickly if the frequency of pulses (they are named *step pulses*) is high. But then the pulse duration must be low. And that is the limit of frequency increasing, it is connected with technology. The thing is that any circuit contains spurious capacity and spurious inductance.

A transistor, for example, has a deficit zone between p- and n-conductor. Thus it can be considered as a capacitor with a low capacity. Such a capacitor cannot be charged or discharged in a moment. If the pulse duration is much more than the time for charging or discharging of the spurious capacitors, pulses aren't corrupted. But if the pulse duration is comparable with the charging time, a pulse can be corrupted as fig. 24.3 shows.

Thus a pulse amplitude can be decreased and a logic "1" may be interpreted as a logic "0".

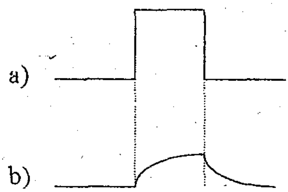

Fig.24.3. A right-angle pulse (a) and it's corruption by a spurious capacity (b).

To avoid this error the spurious capacity of a circuit must be decreased. That's why modern circuits are so miniature. Microminiature modules are not more than 0.5 - 1 sm. length, and they contain 50000 - 100000 transistors. Such circuits can operate very quickly.

COMPLEX RADIOENGINEERING AIRDROME METEOROLOGICAL STATION CRAMS - 2.

The station CRAMS-2 is an automatic station placed at an airdrome. It can measure the following meteorological parameters.

1. Atmospheric pressure - actual pressure and sea-level pressure (it is calculated).
2. Air temperature.
3. Relative humidity.
4. Wind parameters:
   - averaged wind speed for 2 min.,
   - maximal wind speed for 10 min.,
   - maximal wind speed in direction, perpendicular to runway,
   - wind direction.
5. Meteorological visibility range (MVR).
6. Cloud altitude.
7. Near thunderstorm presence.

The station CRAMS-2 can operate automatically. All data are indicated on a special illuminated call-out and printed by teletype. All these data are reported to other airports.

Let's consider the block-diagram of CRAMS-2 station. It is drawn on fig.24.4.

There are transducers in the left column of the picture. Let's divide them by three groups.

1. The transducer placed in the room. It is the transducer of atmospheric pressure (**PT**) only.
2. Transducers placed at meteorological square. They are the following.
   - 2.1. Wind parameter transducer (**WPT**).
   - 2.2. Temperature and humidity transducer (**THT**).
   - 2.3. Thunderstorm transducer (**TT**).
3. Transducers placed near the runway. They are:
   - 3.1. Wind parameter transducer (**WPT**) - the second transducer.
   - 3.2. Meteorological visibility range transducers ФИ-1.

One of them is placed near the middle of runway, two are placed near the beginning and near the end of a runway.

3.3. Cloud altitude transducers PBO-2. They are placed near the beginning and near the end of a runway.

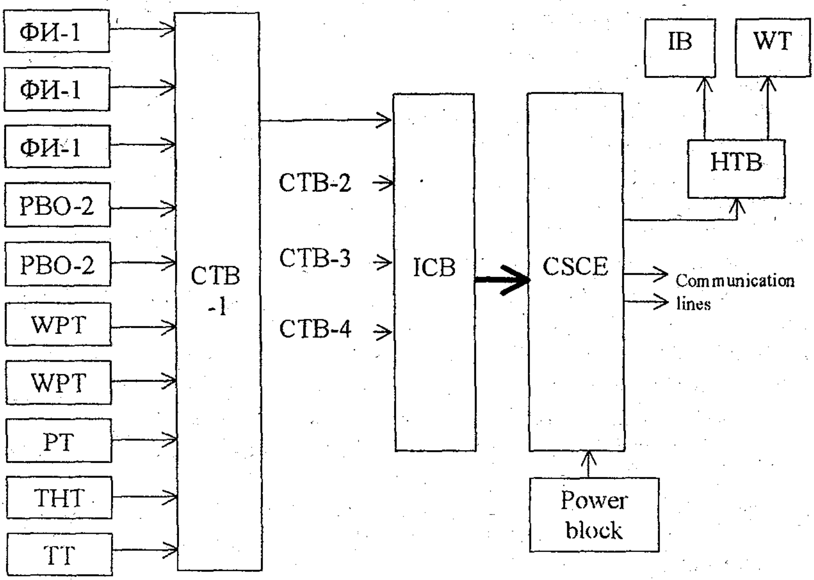

Fig. 24.4. CRAMS-2 block-diagram.

All these transducers are connected with *control and transform block* (**CTB**) by cables. There are four **CTB** in station CRAMS-2. One of them is the main (the first CTB), others are connected only with transducers, placed near runway - another runway. Let's list the functions of **CTB**.

1. Commutation of signals from transducers.

2. A primary data processing - calculations of meteorological parameters and conversion of signals to digital form.

3. CTB contains the operation program, it is written by memory elements.

So, we understand - transducers are connected with **CTB** in turns by commutator, according to operating program. Then signals come to *independence commutation block* (**ICB**). Its functions are:

1. Indication of all meteorological parameters on a special little board.

2. Indication of transducers state (is the transducer connected with **CTB**, it is out of order or not).

Thus we can see all the parameters using **ICB**.

Then signals go to *central special computing equipment* (**CSCE**). Sometimes it is called *central processor.* The **CSCE** functions are following.

1. CSCE contains the program of station operating at all.

2. CSCE commutates signals from CTB.

3. CSCE contains buttons, allowing us to input any parameter by hand.

4. It gives the opportunity to make the operating program by steps.

5. A final data processing.

6. The composition of meteorological telegrams in various codes (BI; METAR; KN-01).

7. The station can be transferred to storm mode and to term mode.

8. The new data can be asked by CSCE.

The CSCE sends signals (telegrams) to *communication lines* - to others airports. Moreover, telegrams are sent to *web teletype.*(**WT**) PTA-80 and to *indication block* (**IB**). Indication block is the illuminated call-out, placed on the wall. All meteorological parameters are indicated there. Web teletype PTA-80 prints on paper web all the telegrams, formed by station. The observer can add a few short words to telegrams, using teletype PTA-80.

All signals pass to **WT** and **IB** through the *hand-input block* (**HIB**). The operator can input any meteorological parameter with this block. It can be done when some transducers (or even CSCE) are out of order.

VOCABULARY

Analog-digital converter (ADC) – аналого-цифровой преобразователь (АЦП)
Low-digit weight – значение младшего разряда
Cap balance – чашечные весы
Balance – гиря
To drive the circuit – запустить схему
Actuation – запуск
Step pulses – тактовые импульсы
Spurious capacity – паразитная емкость
Deficit zone – обедненная зона (например, в транзисторе)
Corruption – искажение
Complex Radioengineering Airdrome Meteorological Station CRAMS – 2 – комплексная радиотехническая аэродромная метеорологическая станция КРАМС – 2
Runway – взлетно-посадочная полоса
Illuminated call-out – световое табло
Teletype – телетайп, телеграфный аппарат
Wind parameter transducer – датчик параметров ветра

Temperature and humidity transducer – датчик температуры и влажности
Thunderstorm transducer – датчик гроз
Control and transform block (CTB) – блок управления и преобразования (БУП)
Independence commutation block (**ICB**) – блок автономной связи (БАС)
Board – (здесь) световое табло малого размера
Central special computing equipment (**CSCE**) – устройство центральное вычислительное специализированное (УЦВС)
Storm mode – штормовой режим
Term mode – срочный режим (обеспечивающий наблюдения в заданные сроки)
Web teletype (WT) – рулонный телеграфный аппарат
Indication block (**IB**) – блок индикации (БИ)
Hand-input block (**HIB**) – блок ручного ввода (БРВ)

Lecture 25.

C R A M S - 2 PRESSURE TRANSDUCER

CRAMS-2 pressure transducer has a 570 - 1090 HPa range. It is placed in a room.

A sensor of pressure transducer is a sylphon, see the fig.25.1.

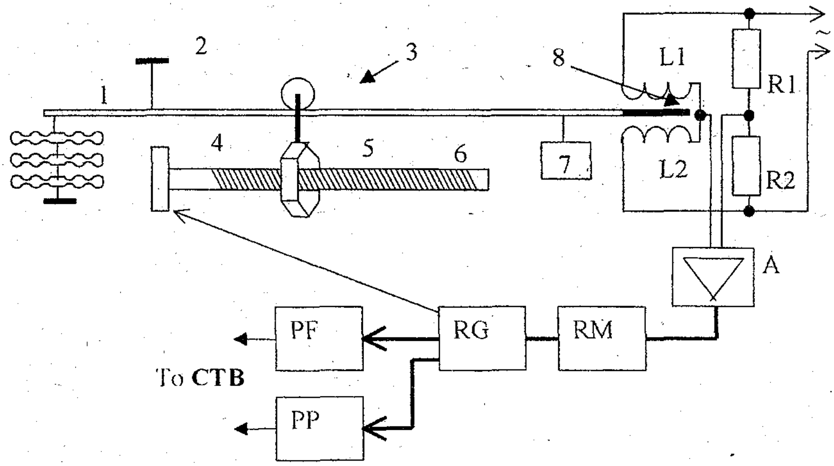

Fig.25.1. The block-diagram of pressure transducer.

The sylphon is connected with a short arm of a level (1). The level support is (2). The long arm has two weights – moving weight (3) and unmoving weight (7). The level's edge (8) is made of ferrite.

When atmospheric pressure (the force from sylphon) puts the level in equilibrium with these weights (3 and 7), the edge (8) has the position we'll call zero. But when pressure changes it is above or below zero. To put the level in equilibrium it is enough to move the weight (3) to the right or to the left. Doing so we notice - each position of the weight (3) corresponds to certain pressure value. Thus atmospheric pressure can be measured. But there are three problems to be solved.

1. How to construct a system for moving the weight (3) when atmospheric pressure changes?
2. How the position of level's edge (8) can be indicated by a system?
3. How the position of weight (7) can be converted to electric signal?

Let's solve the second problem first of all. For indication of level's edge the circuit of zero-indicator can be used. It's a bridge circuit with four arms - L1; L2; R1 and R2. You see, there are two coils L1 and L2 instead of resistors. But pay attention - the circuit has an AC-source of power. As you remember, a coil has an inductive resistance X_L:

$$X_L = \omega \cdot L$$

where ω is a frequency of AC, L is a coil's inductivity. But coil's inductivity depends on presence or absence of ferrite, and it changes when ferrite moves. Thus L1=L2 when ferrite edge is at the equal distances from coils L1 and L2 - at zero position. When it is so, the bridge circuit is balanced. When level moves, bridge circuit isn't balanced and disbalance signal appears. It is AC too, and its amplitude depends upon difference L1-L2. Pay attention - the disbalance signal changes a phase to 180^0 when the difference L1-L2 changes a sign.

This disbalance signal is amplified by the amplifier A. The amplified signal comes to reverse motor RM. RM rotates and the screw 6 is rotated through the reduction gear RG; the last gear is (4). And there is a nut (5) on the screw. It doesn't rotate, it is connected with the weight (3). But when the screw rotates, the nut moves to the left or to the right; it depends on rotation direction. The weight (3) moves with the nut and thus the level tends to equilibrium position. The disbalance signal tends to zero. The reverse motor stops.

Thus we see - pressure transducer is the example of feedback control system. Of course, this feedback is negative, because if disbalance signal appears, this system operates and the signal disappears.

Now let's solve the third problem - to convert the weight's position to electric signal. It is solved with two potentiometers - fine potentiometer (PF) and precision potentiometer (PP). These potentiometers are rotated by reduction gear too, but their angular speeds are different. PP rotates quickly, it makes many revolutions when atmospheric pressure varies over a whole range (from 570 to 1090 HPa). PF rotates so, that it makes only one revolution over a whole range. They are like hour and a minute clock's hands. Thus we have two voltages at potentiometer outputs. Being sent to CTB they carry information about pressure.

This method hasn't such a sylphon shortcoming as hysteresis. The thing is that sylphon doesn't change its size. This method is called *force-compensating method.*

The unmoving weight (7) is used for transducer adjustment. It can be moved by operator during a calibration.

WIND PARAMETERS TRANSDUCER.

Wind parameters transducer is the same, as the device M-63 uses. The only difference is that it has hercons instead of pulsers.

METEOROLOGICAL VISIBILITY RANGE TRANSDUCER.

CRAMS-2 uses pulse photometers ФИ-1 as an MVR - transducer. The voltage from ФИ-1 comes to CTB.

CLOUD BOUNDARY TRANSDUCER.

A transmitter and a receiver of the ceilometer PBO-2 are used in CRAMS-2. But they are connected with a special block, named *cloud boundary transducer*, CBT-block. And this block is connected with control and transform block CTB (see fig.25.2).

This block, CBT, is placed in a room, usually near CTB and CSCE. It makes the following operations.

1. CTB generates signals to fire gas lamp of transducer. The frequency of this signal is 1 Hz.
2. CBT measures a time range from the moment gas lamp flash to cloud signal receiving.

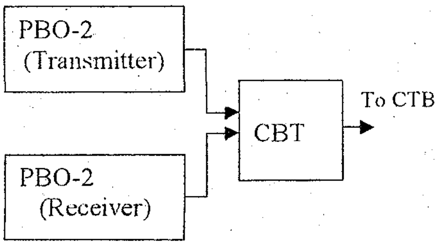

Fig.25.2

3. It transforms signal to digital form.
4. It analyses the signal - overages 8 values of signal and rejects occasional signals (not more than 2 of 8 numbers), when there is a small hole in cloud, or a small cloud on cloudless sky.
5. It indicates cloud altitude on a special indicator.
6. It gives the special signal "1900" to indicator when cloud altitude is more than 1500 m or clouds are absent.

VOCABULARY

Level – рычаг
Support – точка опоры (точка подвеса)
Gear - шестерня
Screw – винт
Nut – гайка
Fine potentiometer – грубый потенциометр
Precision potentiometer – точный потенциометр
Reject – отбрасывать, отбраковывать

Lecture 26.

TEMPERATURE AND HUMIDITY TRANSDUCER (THT)

There is the same transducer for . temperature and humidity measurements. The thing is that psychrometer method is used to measure atmospheric humidity. Thus there are two thermometers - dry and wet. Of course, these thermometers must be remote sensors - thermoresistors, for example. But two difficulties must be solved to construct such a transducer. They are following.

1. How to saturate wet-bulb thermometer (it must be done automatically)?
2. How to measure the humidity in winter, when temperature is below zero?

The first problem is solved by a construction you can see on fig.26.1.

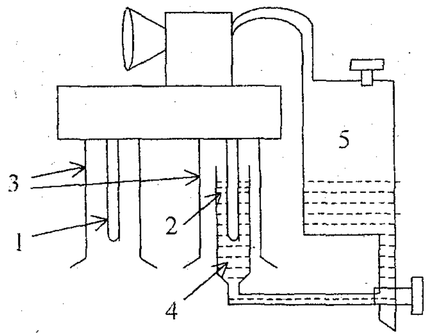

Fig.26.1. Temperature and humidity transducer.

Here (1) and (2) are thermoresistors placed within tubes (3). But the wet thermoresistor (2) is placed to a thin tube (4), connected with a vessel (5) with water. Of course, the water level within the vessel (5) is the same. Thus the thermoresistor (2) is covered by water.

Five minutes before measurements a motor (6) becomes on and air aspirates thermoresistors. But moreover the motor pumps air out of the vessel (5) and the pressure within the vessel decreases. Due to it the water moves out of the tube (4) to the vessel and wet thermoresistor is blown over air. Five minutes later the dry and wet thermoresistor's temperature is measured and the motor (6) becomes off.

As to electrical circuit of the transducer, it is pictured on fig.26.2.

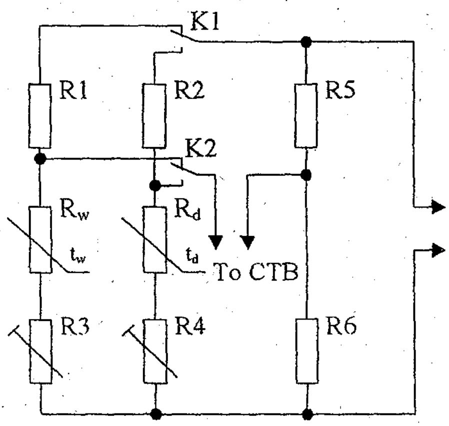

Fig.26.2. Electrical circuit of THT.

When keys K1 and K2 have the upper position the bridge circuit includes resister R1 — (R_w+R5) — R6 — R5, where R_w is the wet thermoresistor. The signal from measuring diagonal comes to CTB. Then keys are switched to lower position and the bridge circuit includes resistors R2 — (R_d+R6) — R6 — R5, where R_d is the dry thermoresistors. The signal coming to CTB depends upon dry thermoresistor temperature t.

R3 and R4 are low-value variable resistors. They are used for adjustment of the circuit.

Such a method is used to measure the humidity when temperature is above zero. But when temperature is not less than -4^0 C (during morning frost, for example) the 4% alcohol solution can be used to prevent water freezing. But when $t < -4^0$ the another method has to be used. It is hair hydrometer you can see of fig.26.3.

Here (1) is a hair guitar. Its lower edge is unmoved, but the upper edge can move up and down. It moves the level system (2) and the axis (3) can be rotated. The spring (4) forces the hair guitar back, thus the angle of axis (4) turn depends on humidity. The pointer (5) shows the humidity with the scale. And a block (6)

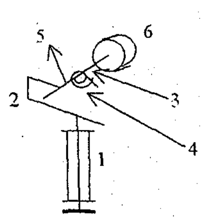

Fig.26.3 Hair hygrometer of THT

converts the angle of axis to a voltage. The circuit of this block is shown on fig.26.4.

A rotor is rotated by axis. An AC is used as a power source for transformer L1-L2. The AC - amplitude at coil L1 is constant. The amplitude of AC at L2 depends on rotor turn. Thus the signal coming to CTB depends on humidity.

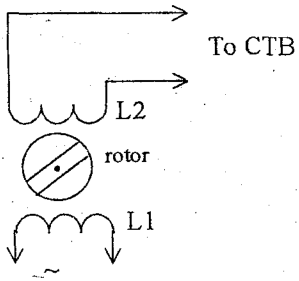

Fig. 26.4.

The precision measurements of THT are 5 % by psyhrometer and 10 % by hair hygrometer. The temperature can be measured from -60^0 up to $+50^0$ with precision measurements 0.2^0.

Let's mention; CSCE calculates dew-point temperature using the program of ROM.

THUNDERSTORM TRANSDUCER

To receive the information about thunderstorm presence we can use electric field step during lightning. A sensor of this transducer is a big plate, placed on the top of the mast 7m altitude. It is the aerial of electrostatic field. Let's consider the aerial's operating.

When there is a charged thunderstorm cloud above the aerial (or not far from airdrome), opposite sign charges come to aerial from the ground (see fig.26.5). They come through an amplifier's input resistor (it is about $10^6\Omega$). When lightning flashes, the cloud discharges partially and electric field steps down. Due to it a part of aerial's charges becomes superfluous. They return to the ground through the amplifier's input resistance. Thus a faint current pulse appears at amplifier's input. We'll call it the *thunderstorm pulse*.

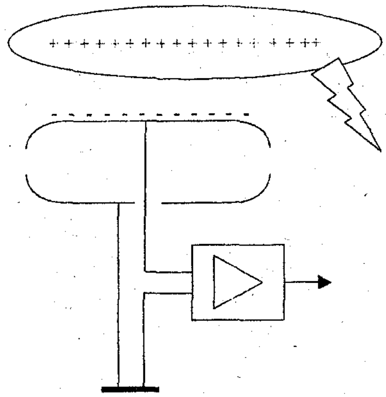
Fig. 26.5. The aerial of thunderstorm transducer.

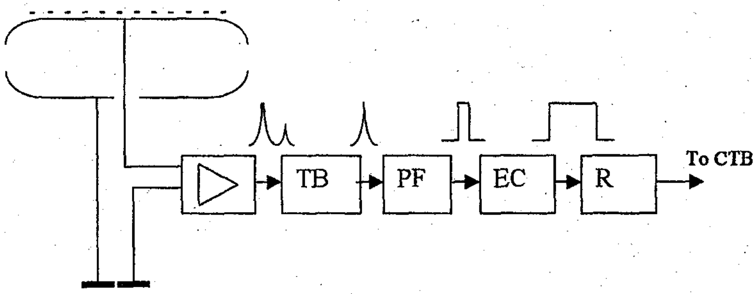

Fig.26.6. Block-diagram of thunderstorm transducer.

Being amplified the thunderstorm pulse comes to ***threshold block*** (**TB**, see fig.26.6). This block solves a problem to separate near thunderstorms and distant thunderstorms. Of course, near thunderstorms causes high pulses, distant thunderstorm causes low pulses (see voltage patterns on fig.26.6). Threshold block passes pulses having the amplitude more than voltage threshold U_{th} . The value U_{th} can be regulated. Thus the radius of observation can be regulated too. Then *pulse former* **PF** generates right-angle pulses when thunderstorm pulse comes to input of PF. *Expansion circuit* **EC** extends the pulse duration to give relay **R** enough time to pick up. Relay's contacts become closed and electric signal comes to CTB. Station CRAMS-2 turns to storm mode.

If thunderstorm pulses wouldn't appear during 15 minutes, station turns to term mode again.

VOCABULARY

Vessel – сосуд
Pump – откачивать
Adjustment – настройка
Alcohol – спирт
Aerial – антенна
Superfluous – лишний
Faint – слабый
Threshold block – пороговое устройство
Pulse former – формирователь импульсов
Expansion circuit – расширяющее устройство

Lecture 27

FACSIMILE APPARATUS (FAXES)

Facsimile apparatus, or faxes, are used to transmit pictures - for example, meteorological maps to electric signal.

Let's look at the basic principles of faxes. How the transmission of a picture to electrical signal can be done? We know photocell and photomultiplier, these elements can convert the light signal to electric form. Suppose, a picture is irradiated by light. The reflected light beam comes to a photocell. But the electrical signal is proportional to integral luminance of a picture. Thus a copy-picture cannot be reconstructed with the aim of this signal.

Let's divide a picture by small areas. Every small area must be illuminated by light and the reflected light beam must be directed to a photocell. Then we'll obtain many electrical signals. Every signal is proportional to optical density of every small area. Thus we'll be able to reconstruct a copy-picture if every area is small enough. The size of any area must be not more than $0.2 \cdot 0.2$ mm. Then the copy-picture will be constructed with small points. But if we'll look at the copy from the distance about 30 sm. (or more), we'll not notice these points. The copy-picture will be good enough.

The turn of signals transmitting must be following. The first is a small area in the left upper corner of the picture, than the area to the right and so on up to the right edge of the picture (see fig.27.1.). It is one *line*. Then the second line below the first and so on up to the down edge of the picture. Such a turn we'll call the *scanning law*.

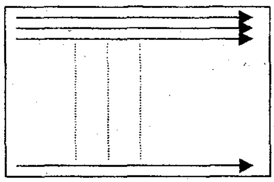

Fig.27.1.

Let's introduce some special terms we'll use speaking about faxes.

1. **Resolving power** (or *resolving capacity*) - a number of elements that can be noticed per length unit of the copy-picture. It is measured in lines per millimeter (l/mm).
2. **Line advance** - the distant between two lines.
3. **Transmission speed**- the number of lines transmitted by time unit. It is measured in lines per minute. It can be easily to understand - the higher is the line advance, the less is the resolving power. The higher is the transmission speed, the less is the resolving power too.

A very important demand is the synchronization of fax transmitter and fax receiver. It means, the scanning along paper has the equal speed in transmitter and receiver. The second important demand is to do it in phase. It means, the beginning of the transmitted line corresponds to the beginning of the received line.
The copy-picture can be good only upon these conditions.
Now let's look at the block-diagram of faxes (fig.27.2).

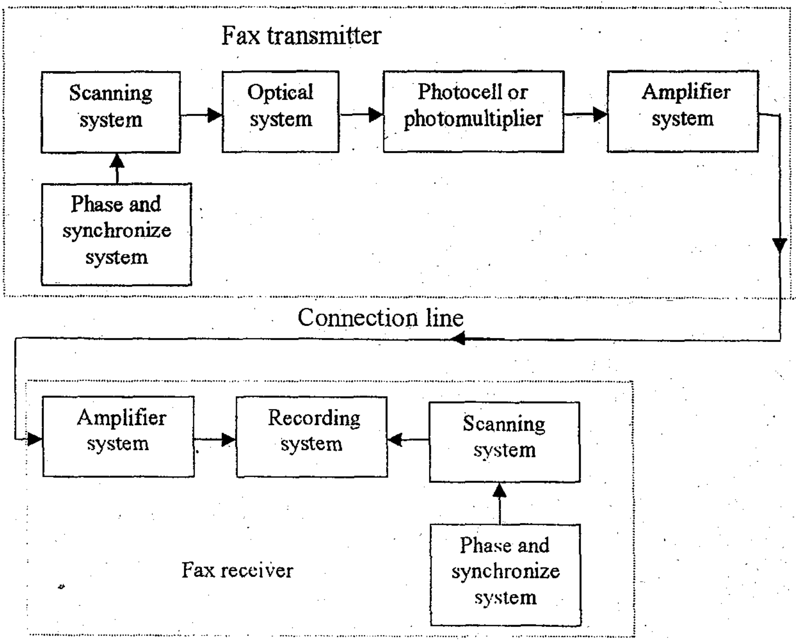

Fig.27.2. The block-diagram of faxes.

The main system of transmitter is *optical system*. It contains a light source, illuminating small areas of original picture and other optical elements. The light beam, reflected by small areas, comes to *photocell* (or photomultiplier). *Scanning system* is to move light beam along the original picture according to scanning law.

Phase and synchronize system generates special signals before the line beginning. The duration of such a signal is 1/18 of line duration.

Let's consider one possible optical system of fax transmitter (see fig.27.3.)

The light beam from the lamp (L) is reflected by mirror (M1) having a hole in center. Then the light beam is focused by moving objective (MO) and passes through mirror system (M2, M3 and RM).

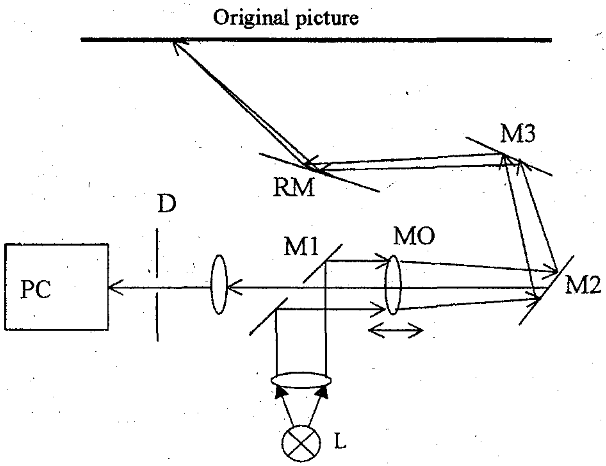

Fig.27.3. Optical system of fax transmitter.

Being reflected by small area of original picture it passes through the same optical elements and through the hole in M1. Then it comes to *photocell* (PC).

Rocked mirror (RM) moves the light spot along the original picture. At the same time original picture is moved by motor and all the picture is scanned by the light beam.

Moving objective (MO) moves to the right and to the left so, that the size of light plot on the picture doesn't change. The diaphragm (D) passes only the light-beam, reflected by small area (0.2 · 0,2 mm).

So, the electrical signal formed by photomultiplier is proportional to the optical density of every small area. This signal is amplified by *amplifier system*. Here the signal is amplified, modulated and so on. This signal comes to *connection line*. It connects fax transmitter and fax receiver. It may be wire or radio connection. But now it doesn't matter for us.

Now let's speak about *fax receiver*. The main system is *recording system* (see fig.27.2). Several methods to record the copy-picture are used. We'll look at *electrochemical method*. It is used in Russian systems.

Suppose a spiral, having only one turn, is rotated by motor (M). The spiral touches a special paper penetrated by solution. The paper is between the spiral and a metal ruler (see fig.27.4.).

Pay attention - only one point of a paper is between the rule and the spiral. This point moves when the spiral rotates. The electrical signal comes to the rule and the current goes through the paper to the spiral. The spiral is grounded.

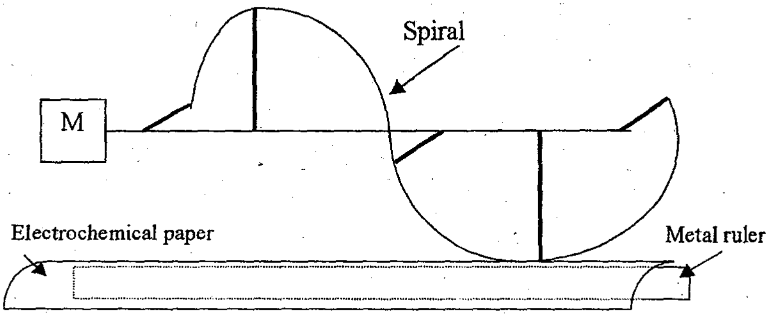

Fig.27.4. The recording system of fax receiver.

When the current passes through the paper, the solution is decomposed and a black spot appears on the white paper. Thus the paper is painted with black points when the current signal goes through it. On the other hand, the paper moves and the lines appear by turn. The copy-picture appears.

To synchronize the transmitter and receiver the special motors are used. The angular speed of these motors depends upon the frequency of AC. Of course, the frequency is absolutely the same.

To make the transmission and the receiver in phase special signals are sent from the transmitter. These signals are recorded by the receiver as a black line. If this black line is at the edge of a copy-picture, that's OK. But if it is at the middle of the line, an operator presses the button "left" or "right". The motor rotates with a speed a bit less (or more) and a black line moves to the edge. It is the system of visual phasing. Of course, this system may be automatic.

The resolving power of Russian faxes is about 2-3 line per millimeter. The transmission speeds are 60, 90, 120 and 240 lines per minute. The line advances are 0.53 or 0.265 mm.

VOCABULARY

Facsimile apparatus (faxes) – факсимильные аппараты
Scanning law – закон строчной развертки
Resolving power – разрешающая способность
Line advance – шаг развертки
Transmission speed – скорость передачи
Electrochemical paper – электрохимическая бумага
Penetrate – пропитывать
Decompose – разлагаться (*хим.*)

Lecture 28.

PERSPECTIVE OF METEOROLOGICAL DEVICES DEVELOPMENT.

The meteorological technology now develops to three directions.

1. The perfection of meteorological sensors.
2. The perfection of calculation methods and data processing.
3. An engineering of new methods of meteorological measurements.

Today we'll speak about only one new method. It is laser measurements.

We have already spoken about laser anemometer. But laser can be also applied for other meteorological measurements. Let's speak about laser emission. This is a pulse emission. It has following properties.

1. It is monochrome emission. It means that wavelength λ = const.
2. It has very small divergence angle.
3. It has very high pulse energy (1 - 10 Mw).
4. The duration of laser pulse (τ) is about $10^{-8} - 10^{-9}$ s, or less.
5. The frequency of laser pulses is 10 - 1000 Hz.

So, the length of the area, illuminated by laser pulse is $\mathbf{L = c{\cdot}\tau}$ ~1m (see fig.28.1.)

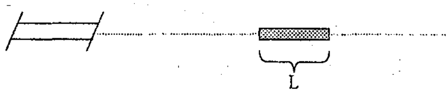

Fig. 28.1.

When laser emission extends in the atmosphere, it is scattered by various molecules, aerosols, drops and so on. A part of this emission can be reflected and thus it returns to earth. The parameters of this part can be calculated, if we know the air composition.

Such a problem is called *direct problem*. But to measure atmospheric parameters we have to solve another problem - to measure laser emission, transformed by air and calculate atmospheric parameters. Such problem is called *inverse problem*. It is very difficult problem. There are following difficulties to solve it.

1. The luminance of laser emission, reflected by air, is very low.
2. The laser emission, reflected by a sounded layer of atmosphere, is transformed by air below.
3. The laser signal may be distorted by our equipment.

That's why laser-sounding devices are very complex and very expensive. But laser sounding has many attractive peculiarities.

1. The distant to sounding area may be as long as 100 km or more.
2. The length of sounding area may be 1 m or less.
3. The sounding time is $10^{-1} - 10^{-2}$ s, so this method is absolutely inertialess.
4. The global monitoring of atmosphere by lasers with satellites can be done in future.

Now let's speak about methods of laser sounding of atmosphere. What parameters can be obtained and how?

1. **Aerosols sounding.** This problem is the simplest. The luminance of laser signal, reflected by aerosols, is rather high. The reflected signal depends of aerosol size, chemical properties and concentration (amount per volume unit). Of course, to calculate all these parameters very complex calculations must be done. The problem is to choose the laser emission wavelength. The radiation must be reflected by aerosols and must not be transformed by atmosphere below.

2. **Atmospheric gases sounding.** This problem is much more difficult, because the luminance of laser signal, reflected by molecules is 1000 time less that the signal, reflected by aerosols. Thus we have to use more sensitive sensors. To isolate a useful signal on a spurious background is a difficult problem too.

The method that is used more often for atmospheric gases sounding, is the *combined scattering method.* The thing is that the light, emitted by illuminated gas molecule, doesn't contain only one frequency. The main frequency $\mathbf{v_0}$ splits and has two side frequencies – $\mathbf{v_0 + \Delta v}$ and $\mathbf{v_0 - \Delta v}$. Thus the spectrum of reflected laser signal has a form, pictured on fig.28.2.

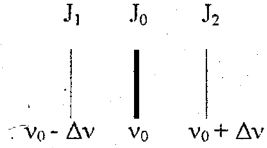

Fig.28.2

The difference $\mathbf{\Delta v}$ depends upon chemical nature of a gas molecule. Thus, to know the chemical nature of a scattering gas we have to measure $\mathbf{\Delta v}$, and to know the concentration (or a partial pressure) of this gas we have to measure the luminance of side lines $\mathbf{J_1}$ and $\mathbf{J_2}$.

There are a lot of problems to be solved. The luminance of line $\mathbf{J_0}$ is low, but the luminance of lines $\mathbf{J_1}$ and $\mathbf{J_2}$ are much less. The various gases have various lines, so spectrums can be superimposed. The atmosphere below must be transparent for all lines J_0, J_1 and J_2.

Fortunately, now laser with a variable wavelength can be constructed. They are most suitable for solving these problems.

3. **Laser sounding of wind.** We have mentioned it before. To sound wind speed and direction the Doppler effect can be used.

4. **The atmospheric pressure sounding.** To sound the atmospheric pressure the combined scattering method can be used. Such gases as nitrogen and oxygen are sounded and the concentration of these gases is to be determined.

5. **The humidity sounding.** The combined scattering method to sound a water vapor is used.

6. **The temperature sounding.** It's a most difficult problem. To solve it the combined scattering method is used too. The radio of line luminance J_2/J_1 depends upon temperature. Of course, we use such gases as nitrogen or oxygen, because the concentration of these gases is high. But the dependence of J_2/J_1 upon temperature is weak thus this sounding must be done very precisely.

Nevertheless laser-sounding methods developes now very quickly.

VOCABULARY

Perfection – совершенствование
Data processing – обработка данных
Apply – применять
Divergence angle – угол расхождения
Extend – распространяться
Scatter – рассеиваться
Direct problem – прямая задача
Inverse problem – обратная задача
Distort – искажать
Peculiarities – особенности
Isolate – выделить
Spurious – паразитный (сигнал)
Combined scattering method – метод комбинационного рассеяния света
Splits – расщепляется

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REFERENCES

1. Ian Strangeways. Measuring the Natural Environment. – Cambridge University Press, Cambridge, UK, 2000. – 365 p.

2. Евтихеев Н.Н., Купершмидт А.Я., Папуловский В.Ф., Скугоров В.Н. Измерение электрических и неэлектрических величин. – М.; Энергоатомиздат, 1990. – 350с.

3.Городецкий О.А., Гуральник И.И., Ларин В.В. Метеорология, методы и технические средства наблюдений. – Л.; Гидрометеоиздат, 1984. – 327с.

4. Качурин Л.Г. Методы метеорологических измерений. – Л.; Гидрометеоиздат, 1985. – 456с.

5. Приборы и установки для метеорологических измерений на аэродромах. Под ред. Афиногенова Л.П. и Романова Е.В. – Л.; Гидрометеоиздат, 1981. – 295с.

6. Стернзат М.С. Метеорологические приборы и измерения. – Л.; Гидрометеоиздат, 1978. – 392с.

7. Матвеев Л.Т. Курс общей метеорологии. Л.; Гидрометеоиздат, 1984. – 751 с.

8. Захаров В.М., Костко А.К. Метеорологическая лазерная локация. Л.; Гидрометеоиздат, 1977. – 317 с.

9. Мержеевский А.И., Фокин А.А. Электроника и автоматика в метеорологии. – Л.; Гидрометеоиздат, 1977. – 382 с.

10. Ковалев В.А. Видимость в атмосфере и ее определение. – Л.; Гидрометеоиздат, 1988. – 215 с.

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