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STUDY OF HEAT TRANSFER FROM HEAT DEPENDENT SEMICONDUCTOR ELEMENTS IN RAREFIED GASES FOR CONTROLLING LOW PRESSURES

A.V.Bulyga, Heat and Mass Transfer Institute,
Academy of Sciences of the B.S.S.R, Minsk, U.S.S.R

Abstract - The study is carried out to reveal the regularities of heat transfer inside heat-dependent semiconductor elements (thermistors) and on their interface with the surrounding rarefied gas. Peculiarities of thermodynamics of thermistor operation in superrarefaction are discussed.

Being the basis for the design of thermoelectrical vacuum gauges, the results obtained are used for the analysis of the sensitivity of the sensing element over a wide pressure range - from the values corresponding to a free molecular flow to the atmospheric pressure which is peculiar of a viscous gas flow.

Nomenclature

α - heat-transfer coefficient;

T, T_S - mean volumetric and surface temperatures of thermistor, respectively;

θ - temperature of the surroundings; $\vartheta = T_S - \theta \cong T - \theta$;

A, B - constants of the material of thermistor;

I - current of thermistor, the surface area of which is S and diameter d;

Nu, Gr, Pr, Kn - Nusselt, Grashof, Prandtl, Knudsen numbers, respectively;

D - diameter of envelope around the heat transfer cylindrical element or the enternal diameter of a boundary layer;

λ_m - heat conductivity of gas at reference temperature $T_m = (T+\theta)/2$;

R - gas constant in $p = \rho R T$, where ρ is density;

c_p, c_v - specific heat of gas at constant pressure and constant volu-

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me, respectively;

g - gravity acceleration;

λ - momentum transfer coefficient.

The high temperature resistance coefficient of thermistors β_T is the main precondition of their use as gauges which are sensitive to the change of the heat transfer conditions [3,6,I3] .

The latter follows from the consideration of sensitivity of the gauge S_x^ϑ, which is determined as a ratio of the change of some output value ϑ to the change of the input value X , i.e. $S_x^\vartheta = d\vartheta/dX$.

Thermistor, as a primary transformer of a nonelectrical quantity into electrical one, may be represented as a series of links each of which represents transformation of one nonelectrical quantity into another one. If thermistor is used as a pressure transmitter of vacuum gauge, its resistance R_T is connected with a pressure p (input value of the transformer) by a series of relations:

$$R_T = f(T) \rightarrow T = \varphi(\alpha) \rightarrow \alpha = \psi(p), \qquad (I)$$

and the sensitivity of this transformer may be determined by the expression [I2]

$$\left.\begin{aligned} S_p^R &= \frac{dR_T}{dp} = \frac{\partial\alpha}{\partial p}\cdot\frac{\partial T}{\partial\alpha}\cdot\frac{\partial R_T}{\partial T}, \\ \text{or} \quad S_p^R &= S_p^\alpha \cdot S_\alpha^T \cdot S_T^R, \end{aligned}\right\} \qquad (2)$$

where in accordance with the data of [6, I3] , the sensitivity of the third link will be

$$S_T^R = \beta_T R_T . \qquad (3)$$

The influence of the heat transfer conditions of thermistors on their electrical parameters is expressed by the coefficient of the dissipated power k .

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Comparing the Newton formula [6, I3]

$$P = \alpha S \vartheta, \quad (4)$$

which expresses the regularities of heat transfer and the formula

$$k = P/\vartheta, \quad (5)$$

which determines this parameter, gives

$$k = \alpha S. \quad (6)$$

It is supposed that the mean-volume temperature T and the surface temperature of the thermistor T_S are equal.

To select gauge and regime of its operation, it is necessary to reveal the physical significance of the parameter k. Having the grounded analytical expression for this parameter, an invistigator may save tedious experiments and thier treatment at numerical determination of k and also it will permit to control its value in certain ranges.

The physical significance of the parameter k is qualitatively clear from the definition. However for the determination of the quantitative relations, it is necessary to consider the components of the dissipated power P.

The power P which is supplied to the thermistor in stationary conditions dissipates by convection and heat conduction P_k through a gas layer and by radiation P_r, and also by heat conductivity along the supply wires P_n, i.e. $P = P_k + P_r + P_n$.

Expressing this relation through the heat transfer coefficients yields

$$\alpha = \alpha_k + \alpha_r + \alpha_n. \quad (7)$$

The component of the heat transfer coefficient α_r can be determined according to the well-known Stefan-Boltzman formula [6]. However the solution of this problem is often difficult as

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the trustworthy data on the thermistor emissivity ε_T are absent. The available data on this problem in the special literature mainly reffer to metals and some non-conducting materials.The data for the semiconductors are almost absent.It is difficult to determine the thermistor emissivity by usual methods which are based on comparison of measurements with the data for the reference standards because of their small sizes.

The above reasons caused the necessity to determine the thermistor emissivity ε_T at such e x perimental conditions when convection is completely absent and heat losses by heat-conduction are more than two order lower than the losses by radiation. Such conditions,allowing us to consider the relative error of determination of ε_T to be not higher than I%,set in vacuum at the pressure of the order 10^{-2} - 10^{-3} $N.m^{-2}$. In this case the heat transfer coefficient α will be expressed as:

$$\left.\begin{aligned} &a)\quad \alpha = \alpha_r + \alpha_n, \\ &b)\quad \alpha_r = \varepsilon_T C_o 10^{-8}(T_S^4 - \theta^4)/(T_S - \theta) = 4\varepsilon_T C_o 10^{-8} T_m^3, \\ &c)\quad \alpha_n = P_n / S(T_S - \theta). \end{aligned}\right\} \qquad (8)$$

The total heat losses P_n through the supply wires are determined as a sum of losses by heat conduction through two semiinfinite rods of an infinite length [6,8]

$$P_n = 2\lambda_n m' f_n, \qquad (9)$$

where λ_n - the heat-conduction coefficient of the wire,with a cross-sectional area of f_n ; $m' = \sqrt{\alpha' U_n / \lambda_n f_n}$;

α' - heat transfer coefficient between the supply wire the perimeter of which is U_n and the surroundings.

After substitution of the value P_n from equation (9) into (8-c) we shall obtain for wires of circular cross-section

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$$\alpha_n = \frac{\pi d_n}{S} \sqrt{\alpha' \lambda_n d_n} \qquad (I0)$$

According to the expirement conditions $\alpha' \cong \alpha_r'$ .Therefore, the values of α' are easily calculated by equaition (8-b) if ε_n is substituted for ε_r and T_m' for T_m where

$$\left.\begin{aligned} T_m' &= (T_n + \theta)/2 , \\ T_n \cong T_m &= (T_g + \theta)/2 \end{aligned}\right\} \qquad (II)$$

The combined solution of equations (8a),(8-b) and(I0)with account of equation (II) with respect to ε_r gives:

$$\varepsilon_r = \frac{1}{\sigma}\left(1 - \frac{\pi d_n}{S}\sqrt{\sigma' \varepsilon_n \lambda_n \alpha_n}\right), \qquad (I2)$$

where $\sigma \cong 4 C_0 10^{-8} T_m^3$; $\sigma' \cong 4 C_0 10^{-8} (T_m')^3$.

The remaine component of the heat transfer coefficient α_κ, which is caused by a joint action of convection and heat conduction is the main,and special expirements are carried out for its determination. For carrying out a test,the unit is constructed of which schemetic drawing is shown in Fig.I. The main assembles of the expiremental unit are two shifted working chambers I and I6,which are placed into thermostate bath 4,vacuum pumps II and I3 and a system of the operating and controlling vacuum guages.

Different sizes of working chambers, in the form of cylindrical glass bulbs 9 and 3 cm in diameter,allow simulation of heat transfer processes of thermistors in conditions of a limited and non-limited space.

The expiremental design allows us to obtain the primary characteristics of thermistors: temperature characteristics and current-voltage ones in the operation temperature range and at the pressures of working medium from atmospheric pressure to I,33 10^{-2} N.m^{-2}. These characteristics are the initial material to reveal the regularities of heat ...

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mistor and on its interface with the surrounding medium in stationary operating conditions. On this unit which has a loop oscillograph, the experimental data are obtained for calculation of dynamic thermistor parameters.

Before proceeding to the description of the experimental investigation of the regularities of heat transfer of thermistors in vacuum, it is necessary to dwell on some pecularities of their operation at the pressures in superrarefaction when the special size of a system becomes small in comparison with the free path length $\bar{\ell}$. The neccessity of such an analysis is caused by appearing disturbances of the gas temperature conditions in superrarefaction that at increased sensitivity of thermistors to the temperature changes can essentialy influence their physical and electrical parameters.

In [2] the relations are obtained which take account of peculiarities of the temperature regime of the superrarefied gas. The measurements of thermistor resistances are carried out for the experimental verification of these relations.

The diagrams plotted according to the experimental and predicted data (Fig.2,3), from which it is seen that in the pressure range from the atmospheric pressure to I3,3 $N \cdot m^{-2}$, the change of pressure does not practically influence, the quantity of thermistor resistance R_{T0} and the material constant B, which is determined from equation [I]

$$R_T = A \exp (B/T) . \tag{I3}$$

In the pressure range from I3,3 to I,33·IO^{-2} $N \cdot m^{-2}$ the values of B calculated by formula (I3) decrease with the drop in pressure and expose their dependence on temperature.

Nevertheless the thermistors resistance does not depend on

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pressure in the conditions of the equality of temperatures of all assemblies of the vacuum system (at the values of $1/T = 3{,}4I3\ IO^{-3}$).With the results obtained,the change of thermistor resistances at drop in pressure should be explained not by the change in the parameter B but by the temperature difference between two connecting vessels in one of which the thermistors investigated are placed and into another one the control vacuum guage is inserted.For confirmation of this conclusion the construction of the experimental unit was changed so that the controlling vacuum gauge and the bulb with the thermistors together with connecting bulbs by tube was placed into a thermostate bath. In such conditions the value of B calculated by resistances of thermistors measured did not change its quantity at all pressures.

The results obtained of the experimental investigation confirmed the truth of the analytical relations obtained and showed that the change of environment pressure does not influence the physical parameters of a semiconductor material of the investigated thermistors.

Besides the electronic nature of the conductivity in thermistors of the type KMT-I and KMT-II is confirmed.

Expiremental Study of Heat Transfer of Thermistors.

Carried out is the series of experiments on study of heat transfer from thermistors in dense and rarefied gas [3] to obtain the initial data at development of the sensitive element of vacuum gauge on the base of the thermistor and determine the interfaces of applicability of criterial equations

$$Nu = \frac{2}{\ln\left[1 + \frac{9{,}37}{(Gr \cdot Pr)^{0{,}25}}\right]} \qquad (I4)$$

and

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$$Nu = \frac{2}{\ln \frac{D}{d} + \beta_1 \left(\frac{d}{D} + 1 \right) Kn}, \qquad (15)$$

To fulfil the problem, the static current-voltage characteristics of thermistors of the type KMT-I and KMT-II are experimentally obtained at an ambient temperature of θ=293,2°K and different pressures. The curves for thermistors of both types (Fig.4) are obtained according to the experimental data.

The pressure range in which the current-voltage characteristics are obtained, includes viscous, molecular-viscous and molecular regimes of free gas flow and allowes us to observe a smooth change of heat transfer parameters in transition from one regime to another.

The experimental data on heat transfer in the conditions of rarefaction are shown in Fig.5 as diagrams $\alpha = \varphi(\lg p)$ and $\alpha_K = \varphi(\lg p)$.

These curves are plotted by the coordinates of current-voltage characteristics, which correspond to the same mean volume temperature T of the thermistor in the whole pressure range. For the thermistor of the type KMT-I a value of 327.6°K was taken for the temperature T, that corresponds to R_T=2I,I5kilohm; for the thermistor of the type KMT-II the temperature corresponds to T=328,I°K (R_T= 442,5 kilohm). At the analytical calculation of α_K, the tentative accomodation coefficients a are taken. For the surfaces of the thermistors and supply copper wires a=0,9 and for the nickel wires a= 0,47. Fig.5 shows that the shape

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of relations $\alpha = \varphi(\lg p)$ and $\alpha_\kappa = \varphi_1(\lg p)$ is approximately the same for the both thermistors. For the qualitative analysis of the results obtained it is convenient to divide these curves into four approximately linear sections.

The first section, to which the molecular regime corresponds of the free flow, includes the pressure range from I,33 10^{-2} to I $N.m^{-2}$. There is a proportional dependence between the parameters α and ($\lg p$).

The second section ($\lg p$ =0,0 - I,6 for the thermistor type KMT-I and $\lg p$=0.0 - 2,4 for KMT-II) corresponds to the molecular - viscous regime. It is characterized by more strong dependence of the total heat transfer coefficient α and its convective component α_κ on $\lg p$ than the first section. The higher sensitivity of the thermistors to the drop in pressure in this range is caused by the presence of a temperature jump on the surface of a solid.

The third section ($\lg p$ =I,6 - 3,8 for the thermistor of the type KMT-I and $\lg p$ =2,4 - 4,4 for KMT-II) corresponding to the viscous regime and partially to the transient region, i.e. to slip flow which is characterized by independence of the convective component α_κ and a slight dependence on the total heat transfer coefficient on the pressure. Some negligibale change α at the pressure change of in the range indicated is the result of change of heat losses through the supply wires. In turn these

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losses change because the temperature jump on the surface of supply wires at higher pressures than on the surface of a thermistor body.

The fourth section ($lg\,p \geq 3{,}8$ for KMT-I and $lg\,p \geq 4{,}4$ for KMT-II) completely corresponds to viscous regime and characterized by the presence of convection in the heat transfer process. The beginning of this section coincides with a value of I.IO^{-3} for $Gr\,Pr = 1 \cdot 10^{-3}$.

The results of the experimental measurements are treated in terms of similarity criteria (Fig.6) that gives possibility to express the results analytically and to compare them with data of other authors [6, IO] .

Theory and Principles of Pressure Gauge Construction.

The analysis of technical characteristics of real constructions of heat dependent pressure gauges [I , 7,9,I2, I4-I6] shows that the proportional increase of the gauge sensitivity does not solve the whole problem of its improvement in all range of the controlling parameter. The main disadvantage of these gauges is as before a pronounced nonlinearity of their static characteristics and, as the result, nonuniform sensitivity which approaches zero in some ranges. The reduction of inertness is the essential problem of the construction of gauges.

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The investigations carried out on heat transfer of thermistors and determination of their dynamic parameters [2,3] have shown that the above problems can be settled by adequate choice of the shape and geometrical sizes of the gauge.

It is not difficult to see this when the static characteristics and sensitivity of a gauge are analyzed and defined .

The analytical relation between the convective component of the heat transfer coefficient α_κ and the temperature T can be expressed from the Newton formula [4] as follows

$$T = \theta + \frac{I^2 R_T}{\alpha_\kappa S}, \tag{I6}$$

which is a static characteristic of the second link. In accordance with the difinition of the sensitivity from formula (2), differentation of relation (I6) over the parameter α_κ upon substitution $\alpha_\kappa = P/S\vartheta$ gives

$$S_\alpha^T = \frac{\partial T}{\partial \alpha} = -\frac{S}{I^2 R_T}\vartheta^2. \tag{I7}$$

The analytical relation between the input gauge parameter p and the heat transfer coefficient α_κ is more complicated and can not be expressed by one equation in a whole range of parameter p.

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For the case of a viscous gas flow we may use the simpliest structure of the heat transfer equation of the type [6]

$$Nu = C\,(Gr\,Pr)^n\,\Phi^m \qquad (18)$$

and solve it with respect to the heat transfer coefficient

$$\alpha_{\kappa 1} = \lambda_m \frac{C}{d}\,(Gr\,Pr)^n, \qquad (19)$$

assuming for simplification the gauge to be an infinite cylinder for which $\Phi^m = 1$. If the values of dimensionless criterion is expressed through the physical gas parameters [6,7] we shall have:

$$\alpha_{\kappa 1} = \frac{H}{d^{1-3n}} \cdot \frac{\vartheta^n}{T_m^{3n}}\, p^{2n}, \qquad (20)$$

where $H = C\lambda_m^{1-2n}(\varepsilon C_v C_p)^n\left(g\frac{M}{R}\right)^{2n}$; $\varepsilon = (9\gamma - 5)/4$; $\gamma = C_p/C_v$

Usually the value I/4 - I/8 [6] does not exceed the numerical values of the exponent $n = f(Gr\,Pr)$ in equation (20) which represents the regularities of heat transfer of real constructions and conditions of the pressure gauge operation. In connection with it, it is more convenient to consider the static characteristic in a semilogarithm scale and thus expression (20) can be given as:

$$\alpha_{\kappa 1} = \frac{H}{d^{1-3n}}\,\frac{\vartheta^n}{T_m^{3n}}\,10^{2n(\lg p)}. \qquad (20a)$$

Hence the sensitivity of the link S_p^α is given by differentation of equation (20a) over the variable $u = \lg p$

$$S_{p1}^{\alpha} = \frac{\partial \alpha_{\kappa 1}}{\partial(\lg p)} = 2Hn\,\frac{S}{d^{1-3n}} \cdot \frac{\vartheta^n}{T_m^{3n}}\, p^{2n}. \qquad (21)$$

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For the pressure range, corresponding to the molecular-viscous regime of the gas flow, the static characteristic of the third link can be obtained in similar manner, expressing the value of the heat transfer coefficient from the formula (I5)

$$\alpha_{\kappa 2} = \frac{2\lambda_m}{L + e/p}, \qquad (22)$$

where $L = d \ln \frac{D}{d}$; $e = (\frac{d}{D} + 1)\frac{\beta_1 \lambda_m}{\varepsilon C_v}\sqrt{\frac{\pi R T_m}{2M}}$; $\beta_1 = \frac{15}{4\pi}\cdot\frac{2-f}{f}$.

Differenting (22) over the parameter $u = \lg p$ we have the sensitivity

$$S_{p2}^{\alpha} = \frac{\partial \alpha_{\kappa 2}}{\partial(\lg p)} = \frac{2\lambda_m e}{(pL+e)^2}\, p. \qquad (23)$$

At pressures, corresponding to the molecular-viscous regime of the gas flow but approaching the viscous one, i.e. when $L \gg e/p$, the formula for the sensitivity S_{p2}^{α} will be

$$S_{p2}^{\alpha 1} = \frac{2\lambda_m e}{L^2}\, p^{-1}. \qquad (24)$$

The same is in the other limiting case when $L \ll e/p$ that corresponds to the free-molecular regime of the gas flow, the sensitivity of the link will be

$$S_{p2}^{\alpha 2} = \frac{2\lambda_m}{e}\, p. \qquad (25)$$

The whole sensitivity of the gauge at different regimes of the gas flow will be determined by expressions:

For viscous regime

$$S_p^R = -2Hn\frac{S}{d^{1-3n}}\cdot\frac{\beta_T}{I^2}\cdot\frac{\vartheta^{2+n}}{T_m^{3n}}\, p^{2n}, \qquad (26)$$

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or substituting $S = \pi d \ell$ we obtain

$$S_p^R = -2Hn\pi d^{3n}\ell \frac{\beta_T}{I^2} \cdot \frac{\vartheta^{2+n}}{T_m^{3n}} p^{2n} \quad (27)$$

For the molecular-viscous regime under the conditions $L > e/p$

$$S_p^R = -2e\lambda_m \frac{S}{L^2} \cdot \frac{\beta_T}{I^2} \vartheta^2 p^{-1} \quad (28)$$

For the transient region of the molecular-viscous regime - $L \approx e/p$ -

$$S_p^R = -2e\lambda_m \frac{S}{(pL+e)^2} \cdot \frac{\beta_T}{I^2} \vartheta^2 p \quad (29)$$

For the molecular regime - $L \ll e/p$ -

$$S_p^R = -2e^{-1}\lambda_m S \frac{\beta_T}{I^2} \vartheta^2 p \quad (30)$$

Formulas (26) - (30) are derived for cylindrical gauges. They may be also used for the analysis of the sensitivity of gauges of different geometry. In the latter case it is necessary to substitute the corresponding characteristic dimension of the gauge into the expression for sensitivity. Thus, in formula (26) for a vertical plate, its height should be taken as a characteristic dimension d. In formulas (28) - (30) instead of $L = d \ln \frac{D}{d}$ the distance should be substituted along the normal between the plate and a wall of a shell, instead of the factor $\frac{d}{D} + 1$ number 2, respectively.

The analysis of the formulas obtained and experimental curves (Fig.6) allows the following conclusions and recommendations to design of pressure gauge to be made.

The gauge sensitivity of a thermoelectric vacuum meter for the measurements within the range from fractions of $N \cdot m^{-2}$ to atmospheric pressure can not be uniform due to considerable quantitative and qualitative variations of the heat transfer regularities through gas in the above range.

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The most nonuniform sensitivity with its very low absolute magnitude is in the region of pressures $5.10^3 - 10^2$ $N \cdot m^{-2}$, which is typical for a transition zone from a viscous flow to the slipping The gauge sensitivity in this region is determined by the relations (27) and (28) which cause contradictory demands of its dimensions variations to increase the sensitivity.

With a purpose of providing the gauge sensitivity similar to the uniform one, this construction may be settled combining two or more sensitive elements of different sizes which may be placed in one ballon.

To decrease the inertia of the gauge and to provide a better thermal equilibrium in the conditions of ultra-rarefaction, it is necessary that the gauge should have the largest possible surface and the smaller possible thermal capacity.

With regard for the latter demand, it is possible to formulate the recommended constructions of gauges.

1. In the viscous regime (at pressure $10^3 - 10^5$ $N \cdot m^{-2}$) a hollow cylinder, a vertical plate.

2. In the molecular-viscous regime ($1,0 - 10^3$ $N \cdot m^{-2}$) - a thin wire or a plate (independent of oreintation), a thin hollow cylinder, a sphere.

3. In the transient and molecular regime (below $1,0$ $N \cdot m^{-2}$) - a thin plate, film, a thin hollow cylinder.

In comparison with the thin film preference should be given to the whole cylinder from consideration of a large mechanical strength. In our opinion the best construction of the gauge is the combination of the hollow cylinder and the fine wire in one ballon.

The given conclusions and recommendations are equally valid for both semiconductor gauges and for the metallic ones.

Deriving the formulae for sensitivity of the gauge, it is supposed that the whole power lost by gauge occurs due to a

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simultaneous action of convection and heat conduction from the surface of the gauge.The investigations have shown that for standard thermistors the heat losses through the supply wires and by radiation from the surface of working substances in the range of their operating temperatures are 50% whole losses and more. If it is taken into account that in accordance with formulae (26)-(30), the sensitivity is inversely proportional to the dissipated power, then the negative influence of auxiliary losses on the sensitivity of the gauge is evident. In addition as follows from these formulae, the sensitivity of the gauge is proportional to the square of a temperature difference ϑ^2 (for the gauge working in the conditions of a viscous flow this proportionality is higher than the second power). Thus, the decrease in the sensitivity may also occur due to the decrease of the temperature difference caused by the auxiliary heat losses.

It is necessary to take into account the other aspect of the influence of the supply wire on the sensitivity of the gauge. Since characteristic dimensions of wires and the gauge body are different at the same pressure, their heat transfer with the surroundings can occur according to different laws and has essential quantitative distinctions. Therefore, the relation $\alpha = \psi(\lg p)$ in fig.5 is more smooth (and hasn't derivatives which are equal to zero) in comparison with the relation $\alpha_k = \psi_1(\lg p)$.

The corresponding choice of geometrical dimensions and physical system properties "supply wire - sensitive element" can rise the sensitivity of the gauge as a whole. Apparently, the supply wires should be very thin and made of the material with a high heat-conductivity.Thus, the gauge is reasonable to be supplied with very thin ribs in the form of plates and films [I5] .

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The temperature difference is the most important parameters, on which the sensitivity and static accuracy of a transformer depends. One measure for a decrease of errors due to change of temperature difference of the gauge is the switching of the differential scheme [I,7,I2,I5] . Sometimes we resort to thermal incubation [I6] or hand-setting of zero [I4]. Here we should analyse the error of measuring ϑ appearing provided that a temperature of a gauge surface T_s is equal to its mean volumetric temperature T . With this purpose the test of a temperature field in the thermistor body is done [4] which is the solution of the heat-conduction equation and its analysis.

Carried out the calculations and analysis [3,4,6] show that the influence of nonuniformity of volume heat emission on the temperature gradient is small and its action is out of the limits of measurement accuracy of mean volumetric temperature.

From the design and the principle of operation of thermistors with metallic contacts-caps we may judge that possible there are three main thermoelectric effects, when electric current passes through the thermistor. We may neglect the effects of Seebeck, Thomson,Peltier on the distribution of the temperature along the surface of the cobalt-manganic thermistors.

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РЕЗЮМЕ

1. Имеется принципиальная возможность обработать данные статических вольт-амперных характеристик термисторов в параметрах процесса конвективного теплообмена. При этом необходим учет потерь тепла излучением со всей поверхности и потерь теплопроводностью с торцов - по подводящим проводам. Влияние градиентов температуры внутри термистора на процессы внешнего теплообмена могут не учитываться. Удовлетворительное совпадение результатов проведенной обработки с теоретическими кривыми и данными других авторов подтверждает правильность выбранной методики учета потерь. Разброс экспериментальных точек является следствием погрешности эксперимента и ориентировочной оценки коэффициентов аккомодации.

2. Учитывая простоту проведения эксперимента при относительно несложной его обработке, и принимая во внимание возможность изготовления термисторов практически любых размеров и конструкций, следует признать целесообразным использовать термисторы как экспериментальные образцы при изучении теплообмена.

3. Получены простые соотношения для статических характеристик и чувствительности датчика теплоэлектрического вакуумметра, выраженные через параметры теплообмена при всех возможных режимах течения газа в условиях естественной конвекции. Анализ полученных соотношений позволил сформулировать рекомендуемые конструкции датчиков.

4. Равномерная чувствительность датчика теплоэлектрического вакуумметра в широком диапазоне измеряемого давления принципиально невозможна. Для создания вакуумметра со шкалой близкой к линейной необходимо использовать несколько датчиков различной геометрической формы и размеров.

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FIGURE CAPTIONS

Fig.I. Experimental Design Scheme.

I - evacuated chamber; 2 - mercury thremometer; 3 - investigated thermistors; 4 - chamber with thermostatic liquid; 5 - depression tube of the thermocouple vacuum gauge; 6 - water chamber; 7 - thermocouple vacuum gauge; 8 - depression tube of ionisation gauge; 9 - ionization gauge; I0 - mercury vacuum gauge of McLeod; II - rotary mechanical pump; I2 - oil trap; I3- diffusion pump; I4 - mechanical standard gauge; I5 - buffer bulb; I6 - shift bulb with thermistors; I7 - oil vacuum gauge; I8- mercury vacuum gauge; I9- mercury traps;20- vacuum two-way cock ; 2I - vacuum straight three-way cocks; 22 - two-stational vacuum straight cocks.

Fig.2. Microcurrent-Voltage Characteristics of Thermistors of the Type a) KMT-I, b) KMT-II at the Different Surroundings and the Different Pressures (U, volt; I, ma). I - $\theta = 273^{o}K$; 2 - 293; 3-3I3; 4 - 333 ; 5 - $353^{o}K$. A - $p =$ I3,3 - IO^{5} $N \cdot m^{-2}$; B - I,33 $N \cdot m^{-2}$; C - I,33.IO^{-2} $N \cdot m^{-2}$.

Fig.3. The Temperature Characteristics of Thermistors (R_T,kilohm; $T^{o}K$). a) thermistor of the type KMT-I; b) KMT-II.

Fig. 4. Current-Voltage Characteristics of the Thermistors of the Type: a) KMT-I; b) KMT-II in the Atmospheric medium at $\theta = 293,2^{o}K$ and Different Pressures $N \cdot m^{-2}$ (U, volt; I, ma). I - IO^{5}; 2 - 6,67.IO^{4}; 3 - 2,67.IO^{4}; 4 - I,33.IO^{4}; 5 - 6,67.IO^{3}; 6 - 2,67.IO^{3}; 7 - I,33.IO^{3}; 8 - 6,67.IO^{2}; 9 - I,33.IO^{2}; I0 - 6,67.IO; II - 4,00.IO; I2 - 2,67.IO; I3 - I3,3; I4 - 6,67; I5 - I,33; I6 - 6,67.IO^{-I}; I7 - I,33.IO^{-I}; I8 - I,33.IO^{-2};

Fig.5.Dependence of the Heat Transfer Coefficient between Thermistors and Rarefied Air at $\theta = 293,2^{o}K$ (α, α_{κ}, w. $m^{-2}.{}^{o}K^{-I}$; $p, N \cdot m^{-2}$).

Indicated values α to multiply by 2 for the thermistor of the type KMT-II.

Fig.6. Heat Transfer from Cylindrical Bodies in the Rerefied gas. I - by the equation (I4) for viscous flow; 2 - by the equation (I5) at $d = 1,9 \cdot 10^{-3}$ m; 3 - the same at $d = 6,4 \cdot IO^{-4}$ m.

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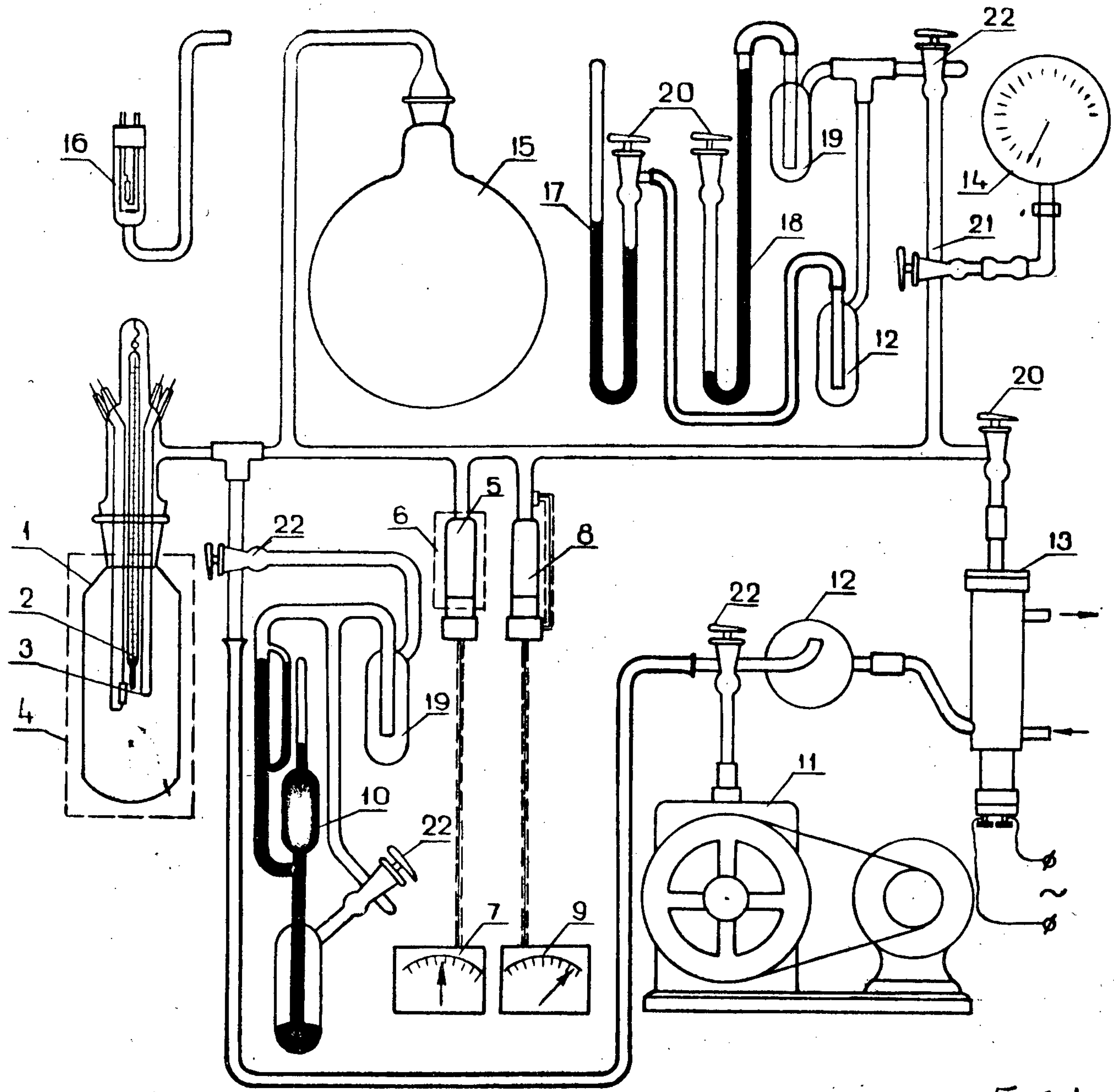

FIG 1

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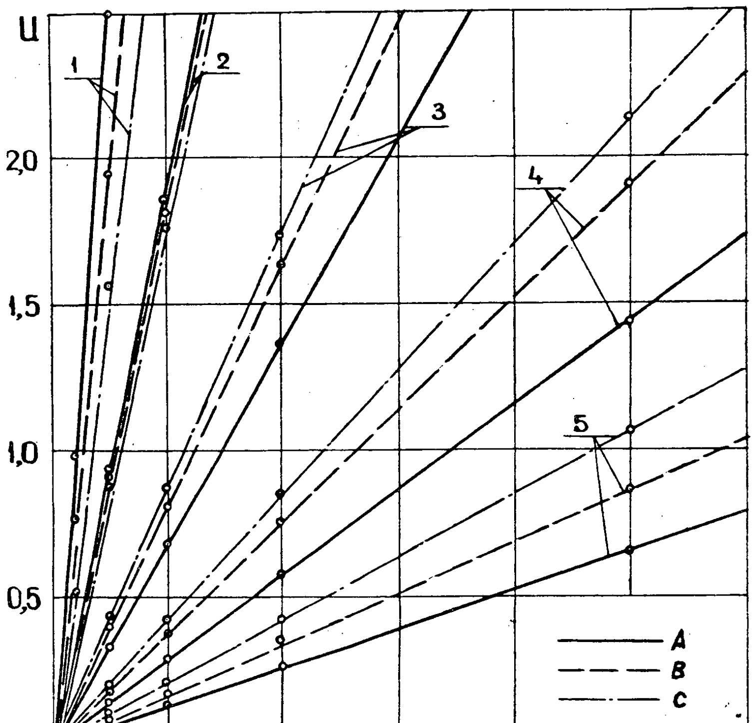
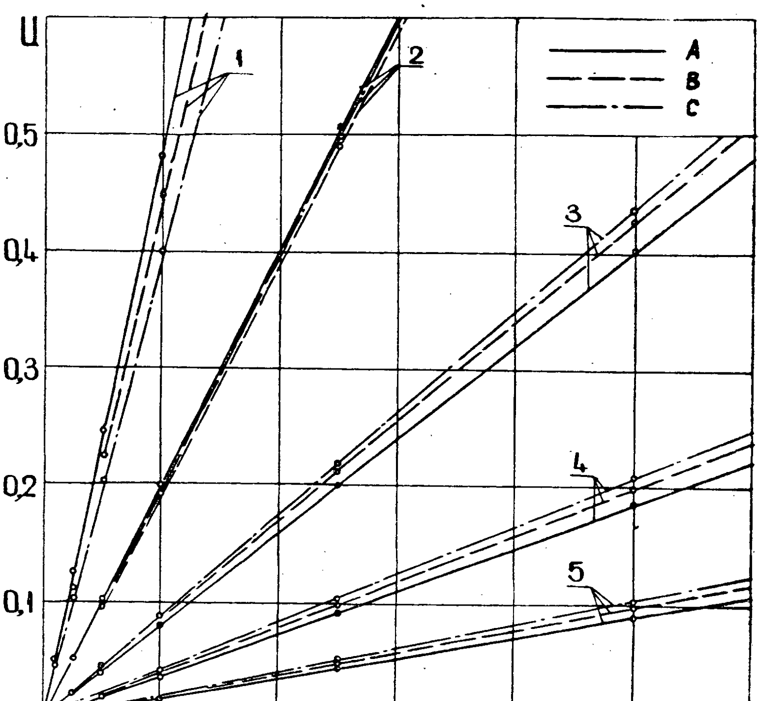
2b



2a



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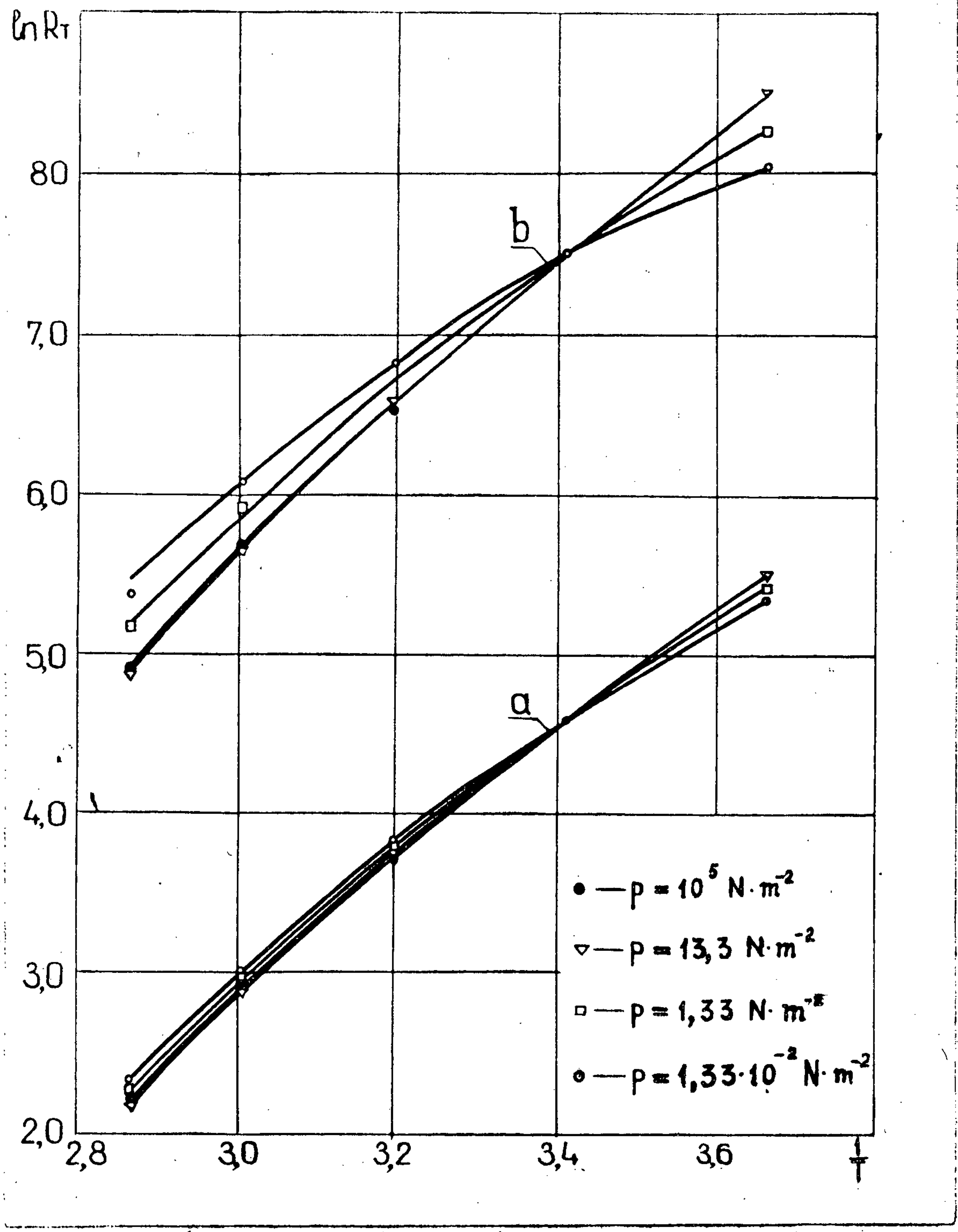

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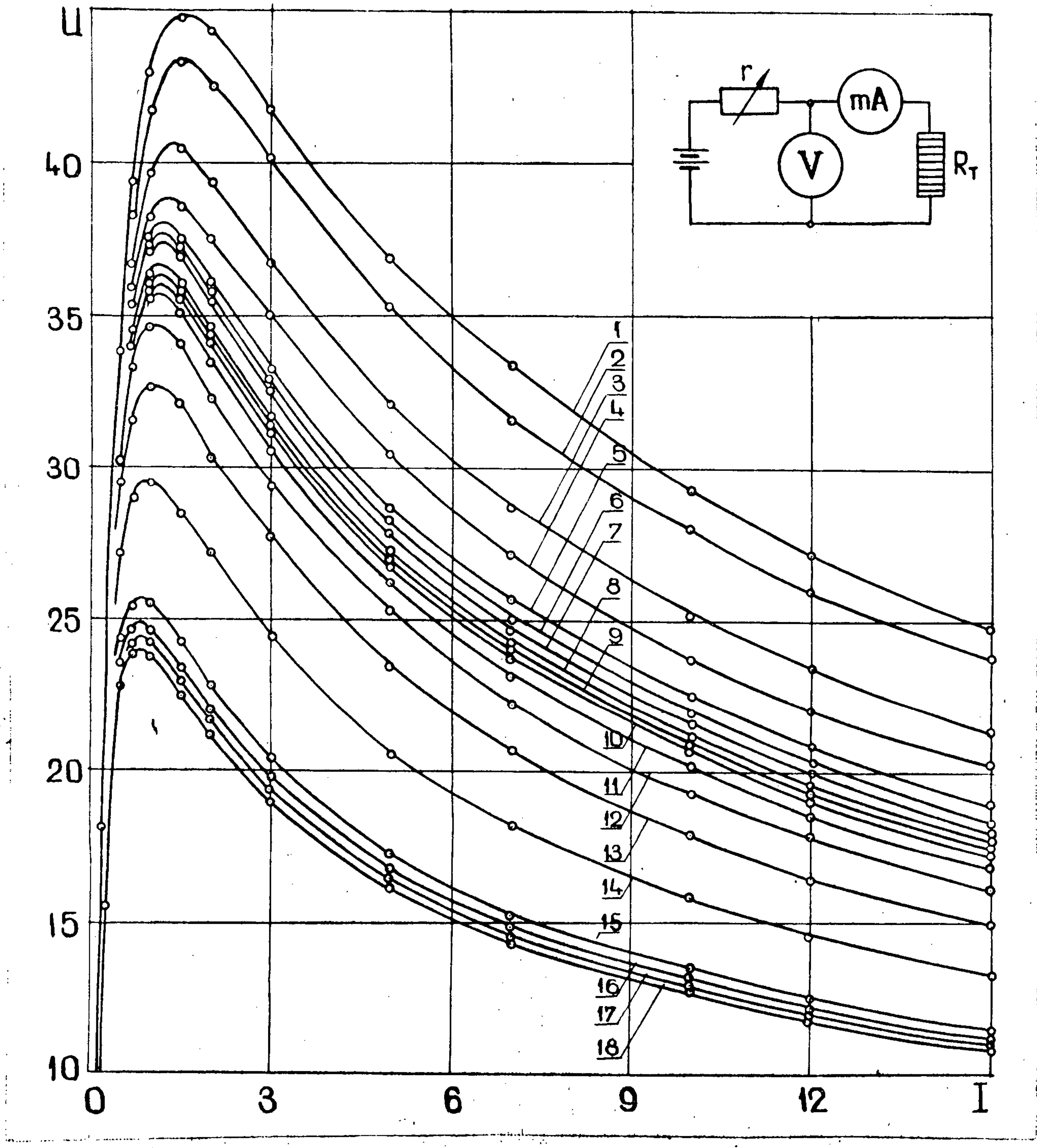

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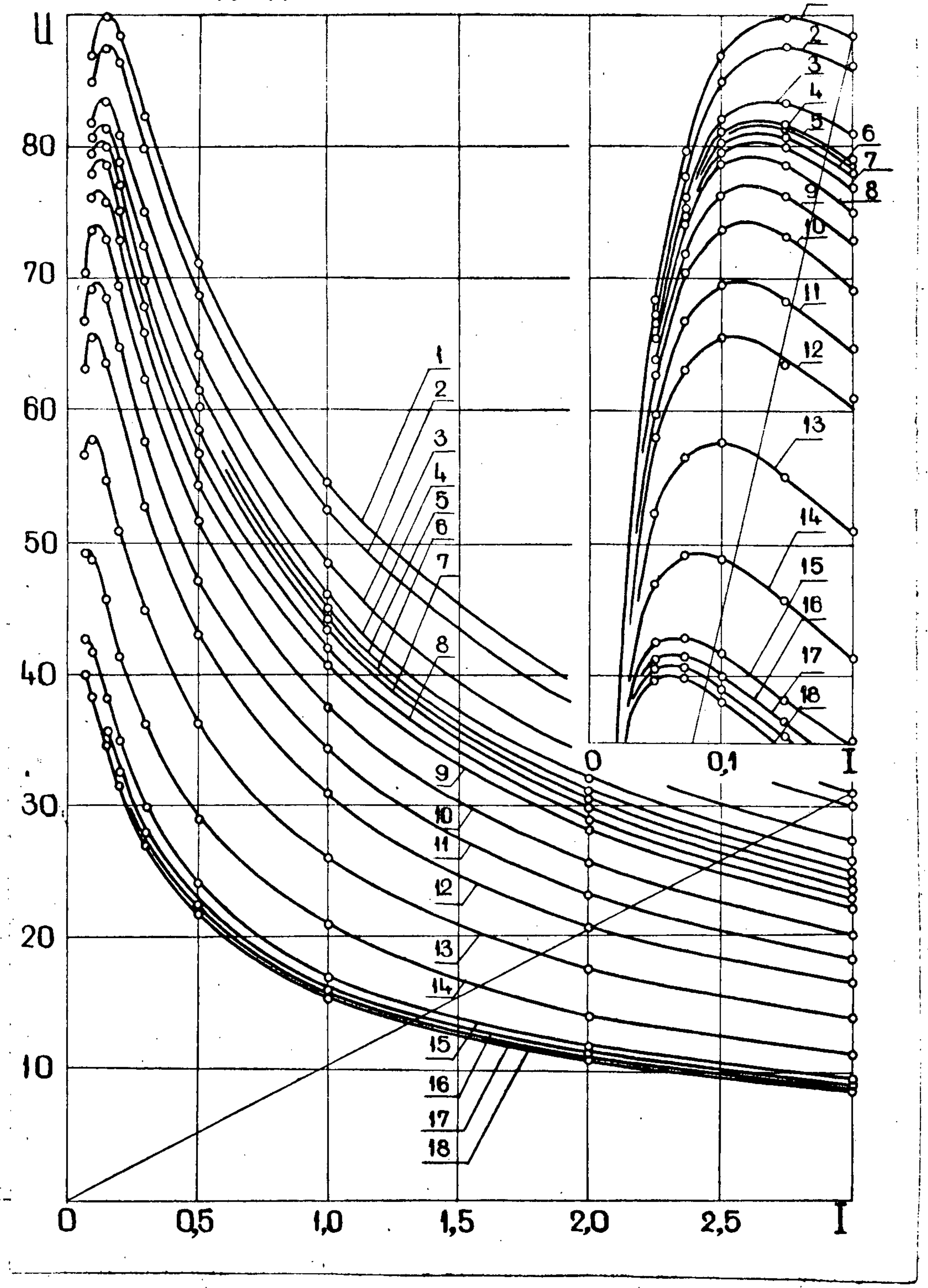

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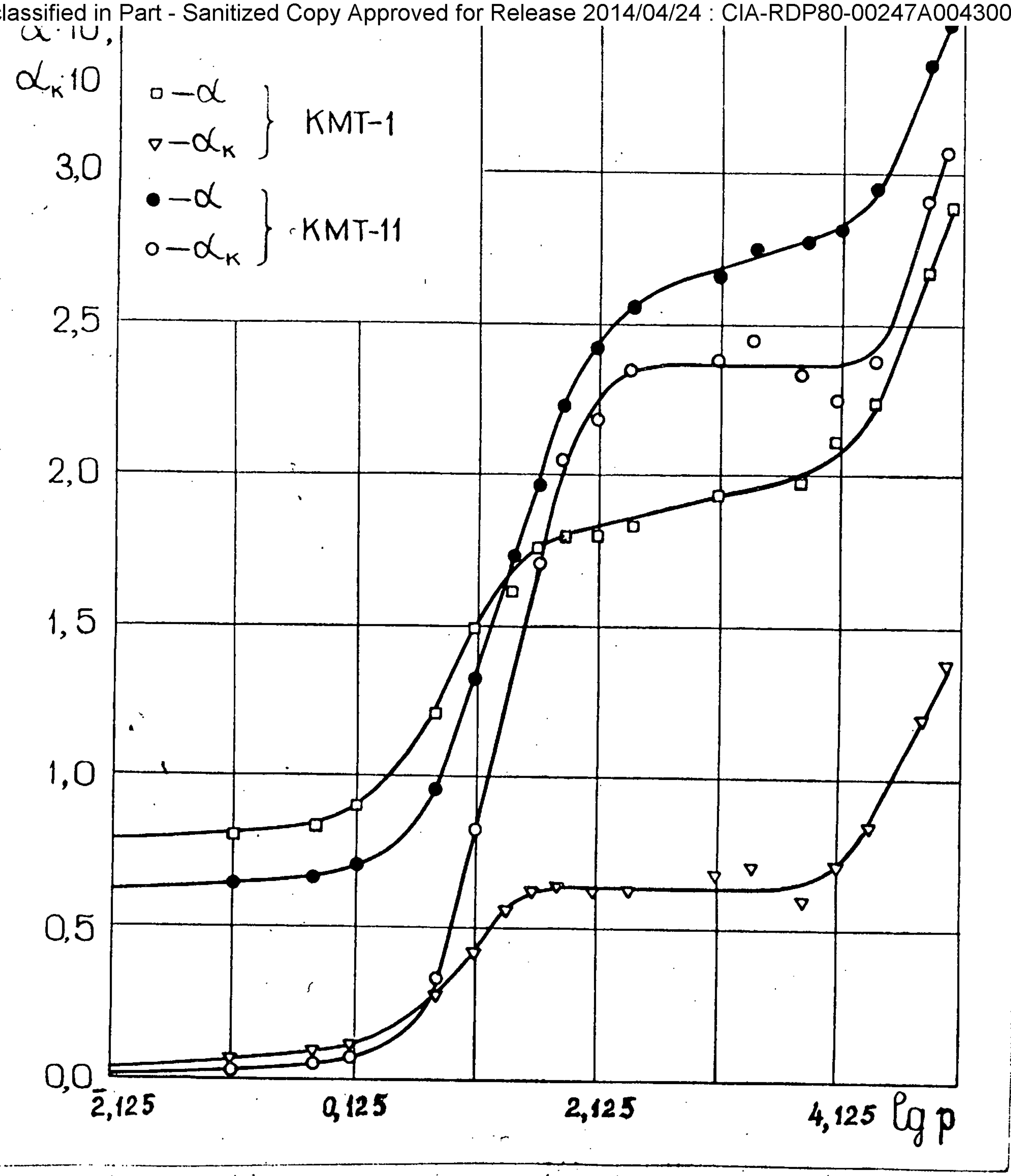

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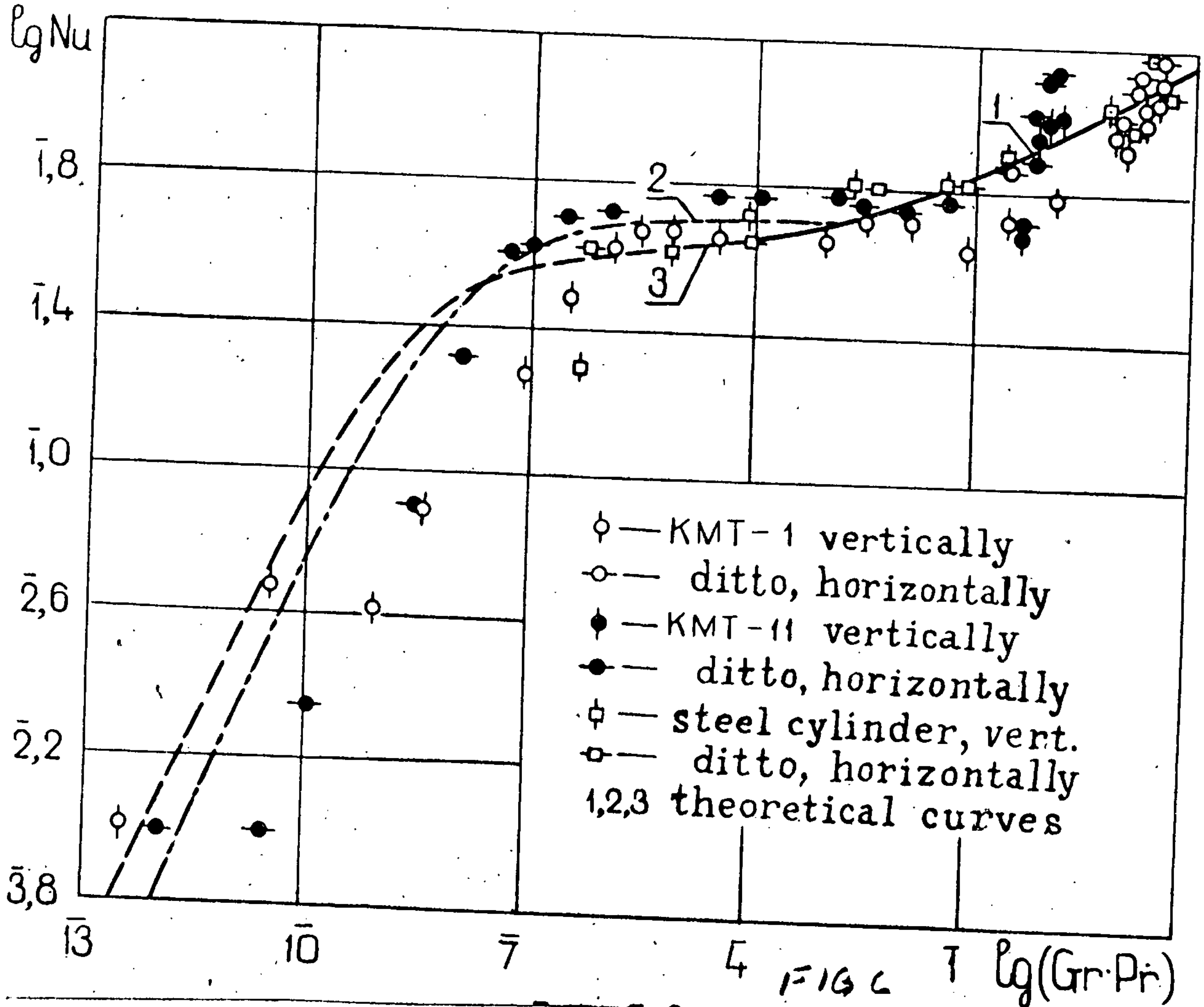

FIG 6

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