and thermal conductivity of ground; α_1, coefficient of heat transfer from medium being transferred to pipe wall; α_{s0}, generalized coefficient of heat transfer from surface to atmosphere; R_0, pipe radius; h_0, depth of pipe axis below ground; t, time; x, y, Cartesian coordinates; α, β, bipolar coordinates.

LITERATURE CITED

1. P. I. Tugunov, Unsteady Operating Conditions of "Hot" Trunk Pipelines [in Russian], VNIIOÉNG, Moscow (1971).
2. B. L. Krivoshein and V. N. Novakovskii, Izv. Akad. Nauk SSSR, Énerget. Transport, No. 6 (1973).
3. I. E. Khodanovich, B. L. Krivoshein, and R. N. Bikchentai, Thermal Processes of Trunk Gas Lines [in Russian], Nedra, Moscow (1971).
4. A. F. Chudnovskii, Thermal Physics of Soils [in Russian], Nauka, Moscow (1976).
5. Ya. S. Uflyand, Bipolar Coordinates and the Theory of Elasticity [in Russian], GITTL, Moscow (1950).
6. A. V. Lykov, Heat and Mass Transfer [in Russian], Énergiya, Moscow (1972).
7. A. M. Aizen, I. S. Redchits, and I. M. Fedotkin, Inzh.-Fiz. Zh., 26, No. 4 (1974).
8. S. G. Mikhlin, Variational Methods in Mathematical Physics [in Russian], Gostekhizdat, Moscow (1957).
9. B. L. Krivoshein, V. A. Yufin, and V. M. Agapkin, Izv. Akad. Nauk SSSR, Énerget. Transport, No. 2 (1976).
10. B. L. Krivoshein, V. P. Radchenko, and V. M. Agapkin, "Unsteady heat exchange of an underground pipeline with an external medium," Paper deposited at VINITI by the editor of Inzh.-Fiz. Zh., No. 331-76.

METHOD OF COMPUTING THE HEAT INFLUXES OVER ELECTRICAL CABLES IN CRYOGENIC SYSTEMS

S. Ya. Milevskii and G. A. Topunov

UDC 621.59:536.33:621.315.2

A method is proposed for computing the heat influx over electrical cables taking account of the dependence of the thermal conductivity of copper on the temperature and radiative heat exchange of the cable and the surrounding surfaces.

One of the fundamental requirements imposed on cryogenic systems is a minimum of external heat influx.

At the same time, a unit of temperature sensors is usually required for checking out and controlling the operation of the system elements. The heat influx over the cables can exert a considerable influence on both the system characteristics and on the readings of the sensors themselves because of the high thermal conductivity of copper, especially at temperatures below 30°K.

Meanwhile, it is usually customary to consider the heat influx over the conductors comprising the cable as though over rods heat-insulated from the side surface, with a constant magnitude of the thermal conductivity, which results in a multiple reduction of the true heat influx, as experiments have shown. As a rule, the low-temperature elements of cryogenic systems are in a vacuum; hence, heat flux by radiation from the surrounding walls proceeds to the side surface of the cable. If Joule heating is neglected because of the smallness of the measuring current through the sensor, the heat-transfer differential equation for the cable can be written in the form

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 33, No. 2, pp. 346-349, August, 1977. Original article submitted July 16, 1976.

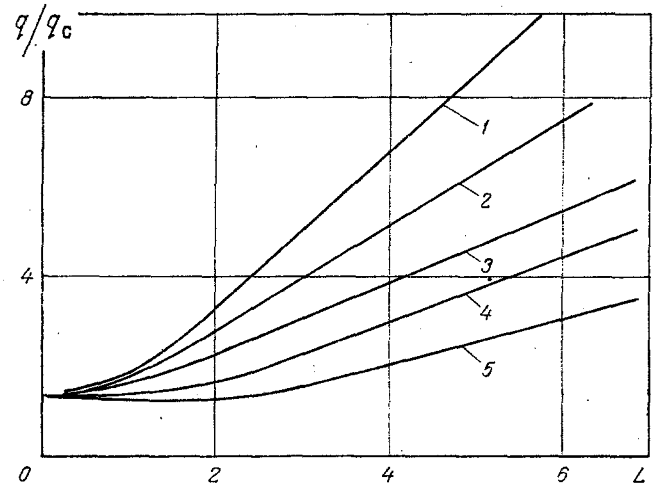

Fig. 1. Dependence of the quantity q/q_c on the parameter L for temperatures of T_0 = 4.2°K and T_l = 293°K at the cable ends. Curves 1-5 correspond to the temperatures T_c = 293, 223, 173, 123, and 77°K.

$$\frac{d}{dx}\left[\lambda(T)\frac{dT}{dx}\right]S+\varepsilon\sigma\left[\left(\frac{T_c}{100}\right)^4-\left(\frac{T}{100}\right)^4\right]P=0 \tag{1}$$

with the boundary conditions

$$x=0,\ T=T_0, \tag{2}$$

$$x=l,\ T=T_l. \tag{3}$$

If we use the notation

$$f(t)=\frac{d\ln[\varkappa(t)]}{dt},\quad h(t)=L^2\,\frac{1-t^4}{\varkappa(t)},$$

Eq. (1) can be converted into the following dimensionless form:

$$\frac{d^2t}{dX^2}+f(t)\left(\frac{dt}{dX}\right)^2+h(t)=0 \tag{4}$$

with the boundary conditions

$$X=0,\ t=t_0, \tag{5}$$

$$X=1,\ t=t_l. \tag{6}$$

By substituting $dt/dX=\sqrt{\theta}$, Eq. (4) is reduced to the linear equation

$$\frac{d\theta}{dt}+2f(t)\theta+2h(t)=0, \tag{7}$$

whose integral will equal [1]

$$\theta=\left(\frac{dt}{dX}\right)^2=\frac{\varkappa^2(t_0)}{\varkappa^2(t)}\left[C-\int_{t_0}^{t}2\frac{\varkappa^2(t)}{\varkappa^2(t_0)}h(t)\,dt\right], \tag{8}$$

where

$$C=\theta(t_0)=\left(\left.\frac{dt}{dX}\right|_{X=0}\right)^2$$

if simplification of the integrating factor

$$\exp\left[2\int_{t_0}^{t}f(t)\,dt\right]=\frac{\varkappa^2(t)}{\varkappa^2(t_0)}$$

is taken into account. Since the absolute value of the heat influx over the cable is computed by means of the relationship

$$q = \lambda(T_0)\left.\frac{dT}{dx}\right|_{x=0} S,$$

we can write

$$\frac{q}{q_c} = \frac{\varkappa(t_0)}{t_l - t_0}\sqrt{C}. \tag{9}$$

Expressing the quantity C from (9) and integrating (8), we obtain the following relationship to compute the temperature distribution along the cable length:

$$X = \int_{t_0}^{t} \frac{\varkappa(t)\,dt}{\sqrt{\left(\frac{q}{q_c}\right)^2 (t_l - t_0)^2 - 2L^2 \int_{t_0}^{t} \varkappa(t)(1 - t^4)\,dt}}, \tag{10}$$

which satisfies the boundary condition (5). The quantity q should be such that the boundary condition (6) would be satisfied; i.e., it is determined from the relationship

$$1 = \int_{t_0}^{t_l} \frac{\varkappa(t)\,dt}{\sqrt{\left(\frac{q}{q_c}\right)^2 (t_l - t_0)^2 - 2L^2 \int_{t_0}^{t} \varkappa(t)(1 - t^4)\,dt}}. \tag{11}$$

Values of the relative heat flux q/q_c as a function of the parameter L, computed by means of (11) on an electronic computer for $\varepsilon = 1$, are presented in Fig. 1 for a number of temperatures of the surfaces surrounding the cable. The computations were performed for cables from PÉV and PÉLShO conductors, which are often used in measuring circuits and are fabricated in conformity with TU (Technical Specification) 16-505, 067-70 from MT brand copper. Because no values of the thermal conductivity have successfully been found for this copper down to 20°K, data for electrolytic copper, presented in [2], were used in the computations. For other brands of copper, the appropriate data for the temperature dependence of the thermal conductivity (some of which is presented in [3]) should be substituted into (11).

The heat influx q tends to a constant quantity which is not dependent on the temperature of the warm end of the cable, but is determined only by the temperature of the surfaces surrounding the cable, as the value of L increases. In this case, the main temperature change occurs on the bounded section of the cable, while the rest has the temperature of the surrounding surfaces. Such a nature of the temperature field along the cable length is confirmed by a computation using (10).

The authors experimentally determined values of the heat influxes over PÉV-2 conductors with a copper diameter of 0.12 mm, 250 and 500 mm length, and a lacquer electrical insulation at the temperatures $T_l = T_c = 293$°K and $T_0 = 37$°K. The magnitude of the parameter L was 3 and 6, respectively. In both cases, the experimental value of the heat influx was 0.022 W, i.e., was independent of the cable length, which is in satisfactory agreement with the quantity 0.021 W obtained by a computation using (11) and is considerably greater than the quantity q_c equal to 0.01 and 0.005 W, respectively.

The investigation performed shows that a careful analysis is needed in each specific case when selecting both the cable size and its location with respect to any elements of a cryogenic system.

NOTATION

T, cable temperature °K; T_0, temperature of the cold end of the cable, °K; T_l, temperature of the warm end of the cable, °K; T_c, temperature of the surfaces surrounding the cable, °K; $t = T/T_c$; $X = x/l$; x, coordinate along the cable axis, m; l, cable length, m; S, total cross-sectional area of the copper conductors comprising the cable, m²; P, perimeter of the cable cross section, m; $\lambda(t)$, thermal conductivity of copper as a function of the temperature, W/m•deg; λ_c, thermal conductivity of copper at T = 273°K, W/m•deg; ε, emissivity of the electrical insulation of the cable; σ, Stefan–Boltzmann constant, W/m²•deg⁴;

$$L = 0.1l\sqrt{\frac{\varepsilon\sigma}{\lambda_c}\cdot\frac{P}{S}\left(\frac{T_c}{100}\right)^3};\ q_c = \lambda_c\frac{T_l - T_0}{l}S,$$

heat influx over the cable without taking account of heat exchange with its side surface for $\lambda = \lambda_c = \text{const}$, W; q, heat influx over the cable, W.

LITERATURE CITED

1. E. Kamke, Handbook on Ordinary Differential Equations, Akad. Verl.-Ges. Geest und Portig, Leipzig (1959).
2. P. L. Powell, H. M. Poder, and W. M. Rogers, J. Appl. Phys., 28, No. 11 (1957).
3. V. V. Senin, Inzh.-Fiz. Zh., 29, No. 6 (1975).

THEORY OF MAGNETIC WATER TREATMENT

V. A. Boichenko and L. G. Sapogin

UDC 663.631:538.24

A mechanism is proposed for magnetic water treatment which makes it possible to explain the known experimental facts. The polyextremal dependence of the treatment effects on the magnetic field strength and the flow velocity as well as the increases in viscosity, thermal conductivity, and the velocity of ultrasound are explained on its basis; specific changes in the IR spectrum of treated water are predicted.

Much time has passed since the discovery of the effect of magnetic water treatment by Vermeiren [1]. Having begun with a decrease in the formation of scale in steam boilers, the magnetic treatment of water and aqueous systems has found wide application in recent years in the most varied fields of practical human activity, since the overwhelming majority of energetic and industrial processes are connected with water. Magnetic treatment is presently used in combating precipitation, in the production of concrete, and in the enrichment of useful minerals, as well as for the intensification of water filtration and purification processes, etc. [2-5].

The numerous studies under laboratory and industrial conditions in recent decades have reliably demonstrated the alteration in the physicochemical processes taking place in water following magnetic treatment: acceleration of coagulation–flocculation of solid particles suspended in the water; the formation of salt crystals during evaporation not on the walls but in the volume; a change in the wetting of solid surfaces, acceleration and intensification of adsorption, etc. [1, 3, 6]. The characteristic features of magnetic treatment should be specially emphasized: a) the necessity of movement of the liquid in the magnetic field; b) the polyextremal dependence of the effects on the water velocity $\vec{v}$ and the magnetic field strength $\vec{H}$; c) the effects obtained are preserved for from several hours to a day.

The main difficulties in understanding the physical bases of magnetic treatment arise because of the smallness of the energy imparted to the water and the enigmatic nature of the mechanism of the "memory" of the water. The energy expended on the treatment is really very small: It is the energy for overcoming the additional resistance in the gap containing the magnetic field. Therefore, the energy states of the water before and after magnetic treatment are quite close but separated by a high energy barrier, the value of which, on the basis of the relaxation time of tens of hours, must be no less than 50 kT.

A possible mechanism for magnetic treatment which permits an explanation of the majority of the known experimental data is discussed below. We consider pure water passing through a transverse magnetic field $\vec{H}$ with a velocity $\vec{v}$. The trajectory of motion of the hydroxyl (OH^-)

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 33, No. 2, pp. 350-355, August, 1977. Original article submitted August 13, 1976.