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IMPROVING ENERGY EFFICIENCY CABLE PRODUCTION

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Abstract. During the energy calculation is made at different temperatures of the heating surface. The influence of the speed of pulling on the cost of the finished products of cable products. The interrelation of speed broaching and temperature of the heating surface.

1 Introduction

The manufacturing process of cables consists of several stages: drawing, cure, drawing, extruding, winding on a spool. The most energy-consuming is the cure. This physical-chemical process takes quite a long time intervals (hundreds of seconds) occurs at a low pulling rate and high temperature heat insulating product. It is also necessary to monitor the temperature of the surface of the insulating layer, which should not exceed the temperature of the beginning of the thermal decomposition of the material sheath.

Each plant produced dozens of cable products. They are classified into solid and stranded, power, installation, monitoring, mine cables, control cables, etc.

Table 1 shows the prices for power cables unarmored several manufacturing plants.

Table 1. Cost of power unarmored cables.

Manufacturer	Brand Cable Products	Cost, ruble/meter
“Content”, Tomsk	VVG 3x1.5	20.90
“Roscable”, Tomsk	VVG 3x1.5	17.85
“ETM”, Tomsk	VVG 3x1.5	22.70

The purpose of this work to reduce energy consumption and improve resource efficiency of production of cable products. To achieve this goal have been resolved following tasks:

1. Determination of the minimum energy associated with a decrease in temperature of the heating surface.

2. Determination of the effect of speed on the energy consumption of production broach.

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2 Problem statements

When setting objectives assumed that the cable is passed through a specialized camera with different heating temperature (543 K, 593 K). It is considered [1], that the output of such a chamber is a product characterized by a high degree of polymerization of the insulating sheath over the entire thickness [1]. The term “complete polymerization” [2] means the end of the chemical process in the insulating layer to the condition $\varphi \approx 1$ (φ - the degree of completion of the main chemical reaction).

As a first approximation considered when modeling the system shown in fig. 1.

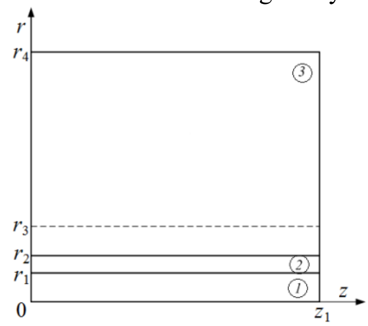

Fig. 1. Scheme for solving the problem of heat transfer area at $0 \le t \le t_p$: *1*-cable core, 2 - cable shell, 3 - the air heating chamber.

It was believed that the cable consists of a core 1 and shell 2. A product with an initial temperature T_0 and constant speed w_c moves through the heating chamber. The shell is heated at a significantly higher temperature 3. Vault chamber temperature (initial temperature of the air in the chamber) T_v taken much more T_0. As a result, overheating of the cable insulating layer is polymerized. Weight completion determined by the degree of polymerization of the insulating material and φ describes the quality of the final product. Time of completion of the polymerization ($\varphi \approx 1$ through the entire thickness ($r_1 < r < r_2$) shell) t_p is the primary integral characteristic of the process.

When setting objectives into account convective and radiative heat transfer mechanisms.

Selecting a cylindrical coordinate system for modeling due to the fact that the cable products are often multi-layered elongated along the axis of symmetry of the long cylinders [3]. To consider setting an axially symmetric (fig. 1).

3 Mathematical model

The system of differential equations of unsteady heat transfer in a partitioned system “heating chamber - air - insulation shell - core cable” (fig. 1), corresponding to the physical formulation of the problem, has the form [4, 5].

Heat conduction equation for the cable core ($0<r<r_1$, $0<z<z_1$):

$$\rho_1 C_1 \frac{\partial T_1}{\partial t} = \lambda_1 \left(\frac{\partial^2 T_1}{\partial r^2} + \frac{1}{r}\frac{\partial T_1}{\partial r} + \frac{\partial^2 T_1}{\partial z^2} \right) \tag{1}$$

The energy equation for insulating cable shell $r_1<r<r_2$, $0<z<z_1$):

$$\rho_2 C_2 \frac{\partial T_2}{\partial t} = \lambda_2 \left(\frac{\partial^2 T_2}{\partial r^2} + \frac{1}{r}\frac{\partial T_2}{\partial r} + \frac{\partial^2 T_2}{\partial z^2} \right) + q_2 \rho_2 \frac{d\varphi_2}{dt}, \tag{2}$$

when $$\frac{d\varphi_2}{dt} = (1-\varphi_2)k_2^0 \exp\left(-\frac{E_{a2}}{R_t T_2}\right). \quad (3)$$

The energy equation for air in the heating chamber ($r_2<r<r_4$, $0<z<z_1$):

$$\rho_3 C_3 \frac{\partial T_3}{\partial t} = \lambda_3\left(\frac{\partial^2 T_3}{\partial r^2} + \frac{1}{r}\frac{\partial T_3}{\partial r} + \frac{\partial^2 T_3}{\partial z^2}\right). \quad (4)$$

Initial (t=0) conditions $T_1=T_0$ at $0\le r<r_1$, $0\le z\le z_1$;$T_2=T_0$ and $\varphi=\varphi_0$ at $r_1\le r\le r_2$, $0\le z\le z_1$; $T_3=T_v$ at $r_2<r<r_4$, $0\le z\le z_1$.

The boundary conditions at $0<t\le t_p$:

$$z=0,\ z=z_1,\ 0\le r<r_1 \quad \frac{\partial T_1}{\partial z} = 0;$$

$$z=0,\ z=z_1,\ r_1\le r\le r_2 \quad \frac{\partial T_2}{\partial z} = 0;$$

$$z=0,\ z=z_1,\ r_3\le r\le r_4 \quad \frac{\partial T_3}{\partial z} = 0;$$

$$r=0,\ 0\le z\le z_1 \qquad \frac{\partial T_1}{\partial r} = 0;$$

$$r=r_1,\ 0\le z\le z_1 \qquad -\lambda_1\frac{\partial T_1}{\partial r} = -\lambda_2\frac{\partial T_2}{\partial r},\ T_1=T_2;$$

$$r=r_2,\ 0\le z\le z_1 \ -\lambda_2\frac{\partial T_2}{\partial r} = -\lambda_3\frac{\partial T}{\partial r},\ T_2=T_3;$$

$$r=r_4,\ 0\le z\le z_1 \qquad T=T_v.$$

Here ρ – density, kg/m^3; C – heat capacity, J/(kg·K); T – temperature, K; t – time, c; λ – thermal conductivity, W/(m·K); r, z – cylindrical coordinate system, m; q_2 – thermal effect of the polymerization reaction, J/kg; φ – polymerization degree; k_2^0 – pre-exponential factor of the chemical reaction, c^{-1}; E_{a2} – the activation energy of a chemical reaction, J/mol; R_t – universal gas constant, J/(mol·K); ν – kinematical viscosity, m^2/s; g – acceleration of free fall, m/s^2; T_0 – the initial temperature of the conductor and the cable shell, K; T_v – primary air temperature in the chamber, K; indexes “1”, “2”, “3” correspond to the core, cable sheath and air in the chamber.

The system of nonlinear nonstationary differential equations (1) - (4) with appropriate boundary conditions is solved by finite difference method [6]. Difference analogues of differential equations (1) - (4) are solved locally one-dimensional method. For solving nonlinear equations, the method of iterations. To assess the reliability of the results of numerical modeling were used algorithms based on the verification of the conservativeness of difference schemes used [7, 8, 9].

4 Results and discussion

Consider energy as the temperature of the heating surface of the Ths1 = 543 K and Ths2 = 593 K speed and pulling cable products υ = 1 m / s.

Electricity tariff of 5 rubles per 1 kW / h at the cable company.

Power the air chamber Vac1 = 27.84 kW, at Ths1 = 543 K.

1 day (8 hours) energy consumption:

$$\Sigma\ \text{con1} = T\cdot V\cdot C=8\cdot 27.84\cdot 5=1113.48 \text{ rubles.} \quad (5)$$

1 month (take 21 working days in a month):

$$\Sigma\ \text{con1m}= T\cdot V\cdot C=8\cdot 27.84\cdot 5\cdot 21=23383.08 \text{ rubles.} \quad (6)$$

Over the year (in 2015 - 247 days):

$$\Sigma\ \text{con1y} = T\cdot V\cdot C=8\cdot 27.84\cdot 5\cdot 247=275059.2 \text{ rubles.} \quad (7)$$

Power the air chamber Vac2 = 32.94 kW, at Ths1 = 593 K.

1 day (8 hours) energy consumption:

$$\Sigma\ \text{con2} = T\cdot V\cdot C=8\cdot 32.94\cdot 5=1317.56 \text{ rubles.} \quad (8)$$

1 month (take 21 working days in a month):

$$\Sigma\ \text{con2m}= T\cdot V\cdot C=8\cdot 32.94\cdot 5\cdot 21=27668.76 \text{ rubles.} \quad (9)$$

Over the year (in 2015 - 247 days):

$$\Sigma\ \text{con2y} = T\cdot V\cdot C=8\cdot 32.94\cdot 5\cdot 247=325447.2 \text{ rubles} \quad (10)$$

Here C - the tariff for electricity, rubles; Vi - power consumption, kW; T - the number of hours of consumption, hours.

By reducing the temperature of the heating surface on the Δ Ths = 50 K savings per year will be:

$$\text{Syear} = \Sigma\ \text{con2y} - \Sigma\ \text{con1y} = 325447.2 - 275059.2 = 50.388 \text{ rubles.} \quad (11)$$

Determine the impact of the speed of the cable pulling on energy products.

Consider υbr1 = 0.5 m / s and υbr2 = 1 m / s at a temperature of the heating surface of Ths = 543 K.

When υbr1 = 0.5 m / s for 1 day (8 hours) to manufacture the cable product length l = 14400 m with υbr2 = 1 m / s – l = 28.800 m.

Energy consumption at the heating surface Ths = 543 K for 1 day will be:

$$\Sigma\ \text{con1} = T\cdot V\cdot C=8\cdot 27.84\cdot 5=1113.48 \text{ rubles} \quad (12)$$

By increasing the speed of pulling, the cost of the finished product is greatly reduced. In this cable polymerization product is uneven, that is the degree of polymerization not all the points of the polymerization layer is close to unity, which in turn reduces the quality of the finished product and have a negative impact on its physical and chemical properties.

5 Conclusion

For the normal process of polymerization of cable products required to comply with several conditions: a small speed broaching and the temperature of the heating surface, which does not exceed the thermal decomposition temperature of the beginning of the shell material of the cable. To improve the energy efficiency of production of cables should greatly reduce the temperature of the heating surface. In turn, with a decrease in the surface temperature of the insulating layer to reduce the feeding speed is assumed, which will increase the cost of the finished products. It is therefore necessary to find a balance between the temperature of the heating surface and the advance speed.

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