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An Effect of Axial Heat Flow on the Distribution of Steady-State Temperatures Along Short Segments of Electric Conductors

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When calculating current carrying capacity of electrical conductors their infinite length is usually assumed .In such a case heat is carried away by convection and radiation. The situation changes when short segments of electrical conductors get heated as then heat flow along the conductor axis occurs, which is of significant effect on the temperature distribution in the wire.

The article presents temperature distribution over short and long segments of electrical conductors.

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Introduction

Temperature determination in real-time systems of electric apparatus conductors or current paths can make a complex task. Analytical results obtained at simple model circuits that as a rule are idealized systems often are of no practical significance for quantitative analysis of heat exchange phenomena in technological systems because of numerous simplifying assumptions that do not match real-time conditions. An assumed conductor is infinitely long while in real-time current paths its length is limited by the device dimensions.

I. Heat transfer ways

In a general case a heat balance equation at convective heat dissipation through the external surface of an infinitely long conductor is described by the Newton's law, which with the Joule effect taken into account, takes the following well-known form [1]:

$$\Delta P dt = cm d\vartheta + hs\left(\vartheta_{gr} - \vartheta_{o}\right)dt \tag{1}$$

where: ΔP – power losses occurring in the considered object s [W/m]

t – time

c – specific heat [W/kg deg]

m – mass of the considered body

ϑ_0 – ambient temperature

ϑ_{gr} – temperature of the heated body

h – heat exchange coefficient [W/m^{2}deg]

s – surface of heat emission from a body of the ϑ_{gr} temperature to its environment of the ϑ_0 temperature

In steady-state conditions and at the assumption that a current path gets heated up to the steady-state temperature of ϑ_{gr} $d\vartheta/dt = 0$ can be obtained. For an apparatus current path power losses ΔP are practically equivalent to resistance losses of the path.. If at the heating with current I current path temperature grows to the limit value of ϑ_{max}, when the resultant path resistance equals R_g then the equation (1) can be written in the following form:

$$I^2 R_g = hs\left(\vartheta_{max} - \vartheta_{o}\right) \tag{2}$$

However, in a general case both the surface heat exchange coefficient h and the resultant path resistance R_g are temperature dependent so:

$$h = f_1(\vartheta) = var \text{ oraz } R_g = f_2(\vartheta) = var$$

When a circuit includes connections of wires of different current-carrying capacity then additional heat transfer along the wire axis occurs and it can be described by the Fourier law [6,7], which means that heat flux density q_n is directly proportional to the temperature gradient ϑ

$$\vec{q}_n = -\lambda \overline{grad\vartheta} = -\lambda \nabla \vartheta = -\lambda n_0 \frac{\partial \vartheta}{\partial n} \tag{3}$$

where: λ[W/(m·K)] – proportionality factor called specific heat conductivity, n_0 – unit vector.

In a thermokinetic system element of the Δl length, like a conductor of the ΔS cross section and specific heat conductivity λ, temperature drop at a segment Δl is the following [8]:

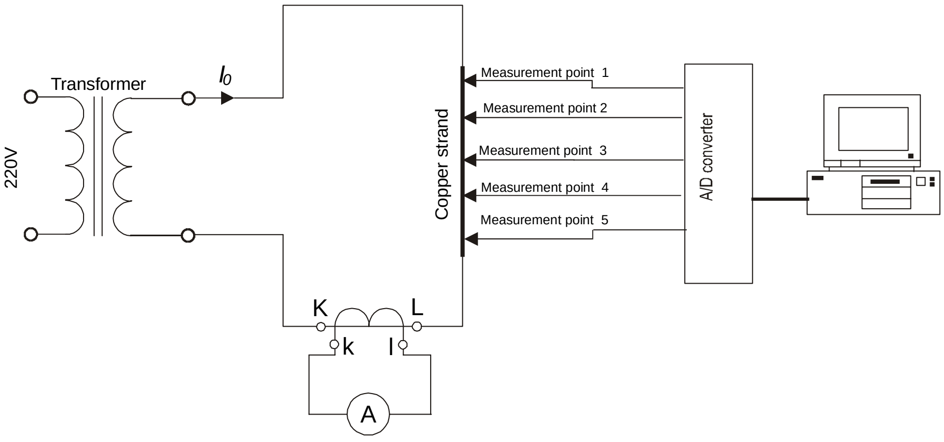

Fig. 1. Measuring circuit

$$\begin{aligned} \vartheta_1-\vartheta_2 &= -\mathrm{grad}\vartheta\cdot\Delta l \\ \vartheta_1-\vartheta_2 &= \frac{q_n}{\lambda}\Delta l \\ q_n &= \lambda\frac{\vartheta_1-\vartheta_2}{\Delta l}=\lambda\frac{\Delta\vartheta}{\Delta l} \\ \Delta\Phi &= q_n\cdot\Delta S \end{aligned} \tag{4}$$

where Φ is a heat flux determined by the heat quantity dQ that flows through a boundary surface S in the time dt. Comparative analysis of the axial heat flow effect on steady-state temperature increments in conductor segments of various lengths has been an objective of the presented work.

II. Distributions of steady-state temperature increments in short segments of electrical conductors

The dependence (2) makes possible to determine temperature increments in electrical conductors only when boundary conditions are neglected i.e. at the assumption that a conductor is infinitely long and heat is given up only in the convective way [2-4].

A measuring stand (Fig. 1) has been used to test heating of electric conductors. The stand is composed of a generating set producing currents up to 1kA and a multi-channel temperature recorder connected to a computer [8]. Temperature measurements have been taken each 0,1 s at five spots of a conductor and the data have been stored as a file into the computer memory. Instantaneous temperature waveforms of individual measuring points could be simultaneously observed at the computer display.

Two segments of a stranded copper wire of the 16 mm^2 cross-section and the length of 1,5 m and 5 m respectively have been tested

Heating up of the tested wire segments proves that apart from convective heat emission axial heat flow related to a considerable current load difference between the tested wires and the feeding ones also occurs [5]. Axial flow brings about differences in the values of steady-state temperature increments in geometric centers and at the ends of the conductors. It can be seen in the both discussed cases of stranded copper wire heating

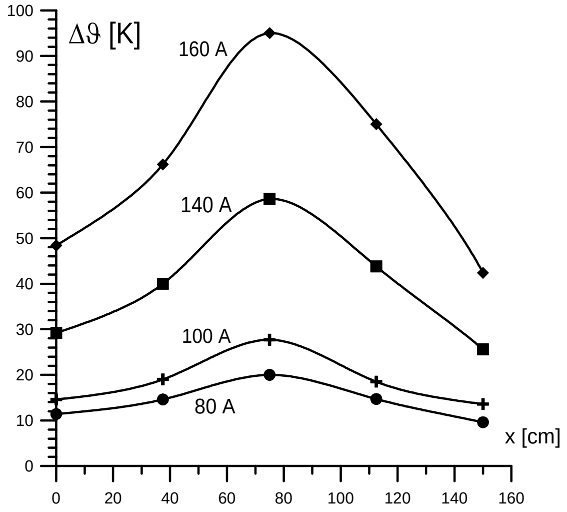

Fig. 2. Distribution of steady-state temperature increments for a 16 mm^2 stranded copper wire of the 1,5 m length

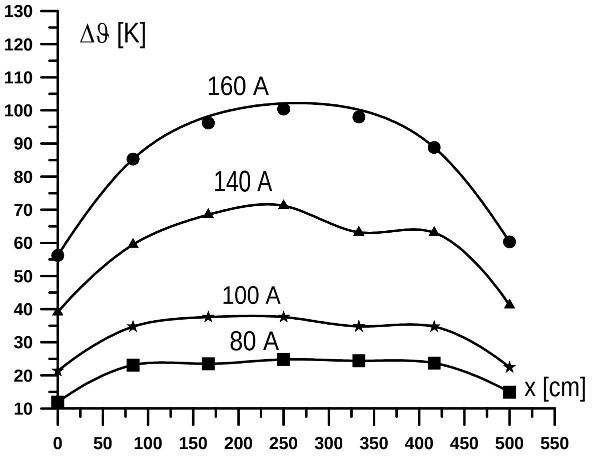

Fig. 3. Distribution of steady-state temperature increments for a 16 mm^2 stranded copper wire of the 5 m length

Tab. 1.

Comparison of maximal increments of steady-state heating temperatures for a 16mm^2 stranded copper wire segments of various lengths

Lp.	Current I [A]	Conductor steady-state temperature increment [K]	
		Length 1,5 m	Length 5,0 m
1	80	20	25
2	100	27	37,5
3	140	58	71
4	160	90	105

(Figs 2 and 3).

In the case of the 1,5 m long wire values of steady-state temperature increments differ over the whole length of the tested conductor, which proves the occurrence of axial heat flow aside with convection. When it is the 5m long wire segment that gets heated the distribution of steady-state temperature increments considerably changes. Temperature increments get stabilized in the wire center and the axial flow effect can be seen only at its ends.

A comparison of maximal temperature values in electric conductor segments of the 1,5m and 5 m lengths (Figs 2 and 3 respectively) proves that at the length of 1,5 m axial outflow occurs over the whole wire length and consequently maximal temperature corresponding to the given load current cannot be obtained. Temperature increment values in a geometric center of the 1,5 m long conductor (Tab. 1) at the average are by 20% lower than the respective values obtained for a longer (l = 5 m) wire.

Conclusions

In a general case depending on the cross-section difference between the feeder conductor and the fed one axial heat flow can occur to the fed wire or out of it, which can bring about changes in steady-state temperatures of a conductor during the current passage.

The obtained test results indicate that axial heat flow should be taken into account when calculating current carrying capacity of short conductor segments. The fact relates to the elimination of additional heat sources that can result from differences in current-carrying capacity of the tested wire and of the feeding one as well as of the junction. In the case of very short conductors fed with wires of high capacity temperature drop over the whole length of the wire of lower capacity occurs and that is why such conductors can carry currents that exceed their nominal values without having allowable temperatures exceeded.

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Ефект осьового потоку тепла на розподілі стаціонарних температур уздовж коротких сегментів електричних провідників

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Обчислюючи пропускну здатність електричних провідників береться до уваги їх нескінченна довжина. таке тепло випадку відносить конвекція і випромінювання. В цьому випадку теплота відводиться за рахунок конвекції та випромінювання. Ситуація змінюється, коли короткі сегменти електричних провідників гарячі, тоді відбувається потік тепла уздовж напрямної осі, який має істотний вплив на температурний розподіл в дроті.

Стаття представляє температурні розподіли в коротких і довгих сегментах провідників.