THE RESEARCH ON THE STABLE TEMPERATURE-RISE OF HIGH-VOLTAGE CURRENT-LIMITING FUSE-LINK

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Abstract: Through the theoretical analysis of nature heat convection between the air and the surface of high-voltage current-limiting fuses in normal service, a mathematical model for the temperature-rise distributing of the surface of the fuse-link is put forward. The results of study show that the temperature-rise has a great difference between the up and down contact of fuse when the fuse-link is fixed vertically, it is proved by the experiment research. The mathematical model and the analysis method could apply to other similar structural appliances.

1. INTRODUCE

Electric appliances will be heated when it in service, especially for fuses. Fuse is a device that by fusing its proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time. It is very important to find a simulation calculation method for the temperature-rise of fuse. On account of complicated structure, the temperature-rise of fuse is difficult to calculate. For example, the electric power loss and heat of fuse-link, the heat conduction of many layers amount the fuse-link, sand stone and insulation bushing, the heat convection between the air and the fuses, The effect of the different mounting on the temperature-rise of fuse-link (vertical or horizontal).

In this paper. Through the analysis of nature heat convection between the air and the fuse, the simulative calculation method of temperature-rise of fuse is obtained, and it is proved by the experiment.

2. THE COEFFICIENT OF CONVECTIVE HEAT TRANSFER

When the fuse is in normal service, The heat exchange is done by the heat convection, here, the dimensionless equation is used to solve the coefficient of convective heat transfer, The Nusselt number equation of nature heat convection defined as[1] :

$$N_u = f(G_r, P_r) \tag{1}$$

and : $G_r = g\beta q l^4 / \lambda \gamma^2$ (2)

where Nu—Nusselt number, dependent dimensionless number;

G_r—Grashof number;

l— Characteristic dimension (m);

q—Specific rate of heat flow(Wm^{-2});

g—gravitational acceleration(ms^{-2});

β—volumetric thermal expansion coefficient (K^{-1});

γ—diffusion momentum(m^2s^{-1}), ;

λ—thermal conductivity($Wm^{-1}K^{-1}$);

P_r—Prandtl number, which has a strong effect on heat convection.

In the dimensionless equation ,some coefficient can be obtained by reference [2], for example, if the reference temperature t=70 ℃, we can know from the index of reference [2] that: λ=0.0296Wm^{-1}℃$^{-1}$, γ=20.02 $\times 10^{-6} m^2s^{-1}$, Pr=0.694.

The coefficient of convective heat transfer (α) is included in Nusselt number, so the Nu is a dependent dimensionless number α can be known from Nu. When the independent dimensionless numbers that includes in the Nu number has be defined. There are different laws to suit Nu. Laminar flow and turbulent flow are described by different experiment relationships under different condition[3].

Laminar flow: $10^5 < Gr \cdot \mathrm{Pr} < 10^{11}$

Dimensionless number:

$$Nu_x = 0.6(Gr \cdot \mathrm{Pr})^{1/5} \tag{3}$$

Laminar flow: $10^{13} < Gr \cdot \Pr < 10^{16}$

Dimensionless number:

$$Nu_x = 0.568(Gr \cdot \Pr)^{1/4} \quad (4)$$

with: $$Nu_x = \frac{\alpha_x x}{\lambda} \quad (5)$$

where Nu_x — Nusselt number;

α_x — Partial coefficient of convective heat transfer ($Wm^{-2}K^{-1}$);

x — coordinate of boundary layer of tube wall.

Coefficients of convective heat transfer are different under vertical and horizontal mount. When the fuse is mounted vertical, the characteristic dimension is the length (L) of fuse. Great change of heat convection has taken place from bottom to top of fuse .The coefficient of convective heat transfer must be described by partial α_x.

$$\alpha_x = \frac{Nu_x \lambda}{x} \quad (6)$$

When fuse is mounted horizontal, The characteristic dimension is the diameter (D), for the diameter is small relatively. Taking the coefficient of convective heat transfer as a constant under horizontal mount, so that an area-averaged value can be defined as:

$$\overline{\alpha} = \frac{5}{4}\alpha_x = \frac{5Nu\lambda}{4D} \quad (7)$$

The α varies around the length of the fuse while the fuse vertical mount. From eqn.(3).(6). The relationship between the α_x and the length x can be calculated the results are shown as fig. 1. the α_x decreases as the length x increases. The conditions heat dissipation are very different between the up and the down for fuse when it is vertical mount.

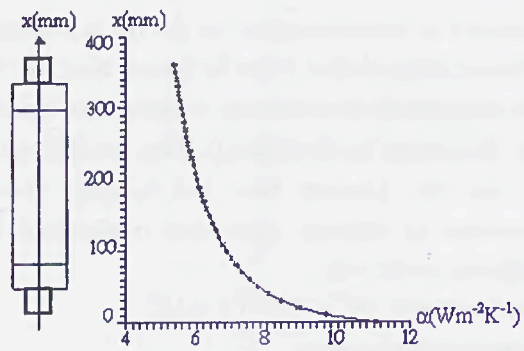

Fig.1 The particular coefficient of convective heat transfer along the wall of fuse-link fixed vertically

3. CALCULATION FOR THE TEMPERATURE-RISE DISTRIBUTION OF FUSE-LINK

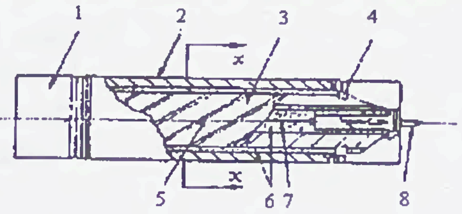

Fig.2 The structure of fuse

1-fuse-link contact cap; 2-insulation bush; 3-star shaped support; 4-airtight; 5-fuse-element; 6- sand stone; 7-striler coil; 8-striker

The structure of H-V current-limiting fuse-link is present in fig.2. The fuse-elements are twisted helicoidal arround a start shaped ceramic support, fuse shell is insulation tube, it is often made up of ceramic. Between support and bush, sand stone are filled up .

The fuse-link can be simplified as a bar in order to calculation T, shown on fig.3. The fuse-link is symmetry on the center. L_2. the section between L_1 to L_0 is fuse's metal contact cap of fuse, the section from L_0 to L_2 is ceramic bush. The temperature-rise distribution of fuse-link can be divided into two part to calculate. Q the internal source, dx the calculus element; S the section area. P the circumference. λ thermal conductivity, T temperature-rise.

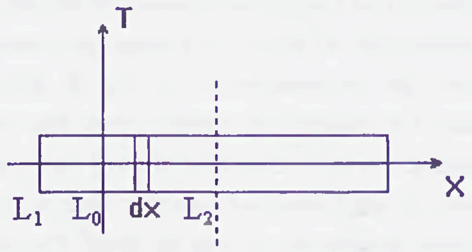

Fig.3 The coordinate of the axial temperature-rise distribution of fuse-link

$$\frac{d^2T}{dx^2} - \frac{\alpha P}{\lambda S}T + \frac{Q}{\lambda} = 0 \quad (8)$$

The solution of eqn.(8)as follows :

$$T = T_w + C_1 e^{mx} + C_2 e^{-mx} \quad (9)$$

Where coefficient C_1,C_2 can be obtained from the boundary condition. For the part of conductor, S_1 the section area; $P_1$the circumference. λ_1 thermal conductivity, T_1 temperature-rise. θ_1 the stable temperature-rise of conductor far from fuse, boundary condition is presented follow:

$$\begin{cases} T\big|_{x=-\infty} = \theta_1 \\ \dfrac{dT_1}{dx}\big|_{x=-\infty} = 0 \end{cases} \tag{10}$$

For the part of ceramic bush, S_2 the section area; P_2 the circumference. λ_2 thermal conductivity, T_2 temperature-rise. θ_{max} the highest temperature-rise of fuse, the boundary condition is given:

$$\begin{cases} T\big|_{x=L_2} = \theta_{\max} \\ \dfrac{dT_2}{dx}\big|_{x=L_2} = 0 \end{cases} \tag{11}$$

At L_0 the temperature-rise of fuse is assumed as θ_0, the boundary condition is given:

$$\begin{cases} T_1 = T_2 = \theta_0 \\ \dfrac{dT_1}{dx} = \dfrac{dT_2}{dx} \end{cases} \tag{12}$$

Through deduced and solved, the different sections of temperature-rise distribution are given

$$T_1 = \theta_1 + (\theta_0 - \theta_1)e^{m_1 x}$$

$$(L_1 \le x \le L_0) \tag{13}$$

$$T_2 = \theta_2 + \frac{\theta_{max} - \theta_2}{2}\left(\frac{e^{m_2 x}}{e^{m_2 L_2}} + \frac{e^{m_2 L_2}}{e^{m_2 x}}\right)$$

$$(L_0 < x < L_2) \tag{14}$$

where, m_1 、 m_2 、 θ_0 、 θ_1 、 θ_2 (θ_2 the stable temperature-rise far from the θ_{max}) are known termes, they are given

$$m_1 = \sqrt{\frac{\alpha_1 P_1}{\lambda_1 S_1}}; \qquad m_2 = \sqrt{\frac{\alpha_2 P_2}{\lambda_2 S_2}};$$

$$\theta_0 = \frac{m_1\theta_1(e^{-m_2L_2} + e^{m_2L_2}) - m_2\theta_2(e^{-m_2L_2} - e^{m_2L_2})}{m_1(e^{-m_2L_2} + e^{m_2L_2}) - m_2(e^{-m_2L_2} - e^{m_2L_2})}$$

$$\theta_1 = \frac{Q_1 S_1}{\alpha_1 P_1}; \qquad \theta_2 = \frac{Q_2 S_2}{\alpha_2 P_2};$$

$$\theta_{\max} = \theta_2 + \frac{2(\theta_0 - \theta_2)}{e^{-m_2L_2} + e^{m_2L_2}}。$$

According to the symmetry principle, the temperature-rise of the other part of fuse-link can be known, The inter heat sources Q(Wm^{-3})can be obtained follow:

$$Q = I^2R/V \tag{15}$$

where: I(A) the current, R(Ω) the resistance of fuse, V(m^3) the volume of conductor that produces heat.

4. CALCULATION AND TEST

To validate the mathematical model, some comparisons between experiments and calculation results have been made. Rated current of the fuse is 100A; The resistance is 5×10^{-3} Ω. The diameter is 76.2mm, the length is 360mm. The temperature-rise is measured by thermocouple method. Two different mountings (horizontal and vertical) are tested under 100A current for fuse-link sample. The comparisons between experiments and calculations have been performed with the results presented fig.4, fig.5. According to the mathematical model, the calculation results are shown as the curve 2 in fig.4 and fig.5. A good agreement observed on fig 4, fig.5 between experiment and calculation. The No.3 in the two fig is the symbolization of fuse-link . The length of fuse-link is signified by axis x. The temperature-rise of fuse-link surface is signified by axis Y.

In the fig.4, the fuse-link mounting horizontal, the stable temperature-rise distributes symmetry center, the center temperature-rise is the highest, the calculation is 112K, the value of measurement is 119K,the error of calculation is 5.8%. The temperature-rise of two contact caps is the same as 41K.

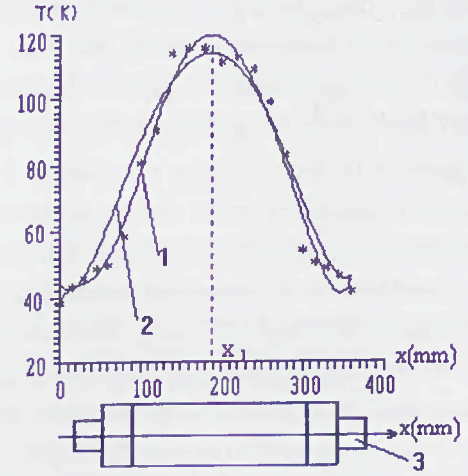

Fig.4 The temperature-rise distribution of fuse-link fixed horizontal

1—experiment; 2—calculation 3—fuse-link

In fig.5 when the fuse-link mounted vertical in serves. The highest temperature-rise is above the center, the T of up contact is greater than the down. The distribution of stable T is unsymmetrical. At the X_2=220mm, It has the highest temperature, the value of calculation is 107K, the value of experiment is 114K, the error of calculation is 5.7%. The temperature-rise of up contact cap is 62K, and the down contact cap is 34K. It is above one times of temperature-rise between the up and down contact cap.

It is different that the stable temperature-rise distribution of fuse under horizontal and vertical

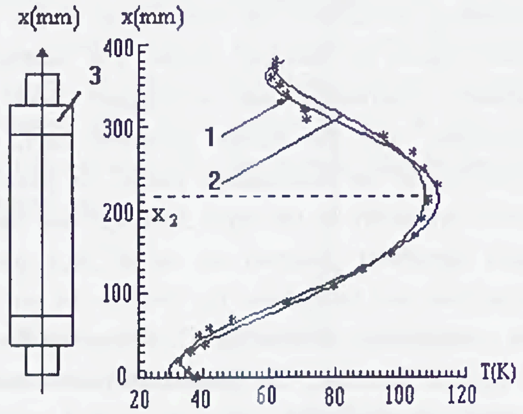

Fig.5 The temperature-rise distribution of fuse-link fixed vertically

1—measurement; 2—calculation;3—fuse-link

mounting. When fuses are withstanding the same current,

This case can be explained by the heat convertion condition. The characteristic dimension is fuse's diameter (D), in horizontal mounting. The (CD) is fuse's length (L) in vertical mounting. Because the diameter (D) is very small, the α of horizontal fuse is determined by the diameter D. From equation (7) , taking $\bar{\alpha}$ for α, which is a constant. It means that the condition of the heat convection is the same for two tops of fuse.

When fuse is in vertical orientation, the α varies the inverse of the length l, from fig.1 we known that the α of two tops are different. The α of up contact cap is smaller than the α of down. So the closer to the up contact cap is, the smaller the heat exchanges. The T of up of fuse is higher than down. The T distribution is unsymmetry.

5. CONCLUSIONS

A mathematical model for temperature-rise distribution of the fuse-link is put forward by theoretical analysis. Different a equation has be presented to suit different mounting of fuse-link.

The T distribution of fuse-link is symmetry under horisontical mounting. When the fuse-link is installed vertical, T-r distribution is unsymmetry, it is because that the α varies from bottom to top. The calculation has been validated by test.

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Jin Lijun was born in Zhejiang China in 1964. He received B.Sc., M.Sc. degrees in Xi'an Jiaotong University in 1987,1997 respectively. Now he is studying in Xi'an Jiaotong University as a doctor candidate and engaging in the study of "Self-Adapting Intelligent Control Device of High Voltage Circuit Breakers "

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