

TEMPERATURE DETERMINATION IN ELECTRIC ARC

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ABSTRACT

This paper deals with approximate determination of temperature radial distribution in an electric arc plasma by means of numeric processing of experimental results, obtained in experiments with the model of extinguishing chamber of SF₆- high voltage circuit breaker. MATLAB computer program has been created based on the numeric solution of Ellenbaas-Heller equation. This program will be used in practice training within the master course Plasma Physics and Diagnostics.

1. INTRODUCTION

The model of the extinguishing chamber of SF₆- high voltage circuit breaker has been designed and produced in VUET – ETD Doudlevec. It has enabled to follow behavior of electrical and mechanical parameters of the switching process. The equidensitometry evaluation of switching arc images (Fig. 1) has completed the results with the time behavior of the arc form, so the data for determination of temperature radial variation in specific instant of time has been obtained.

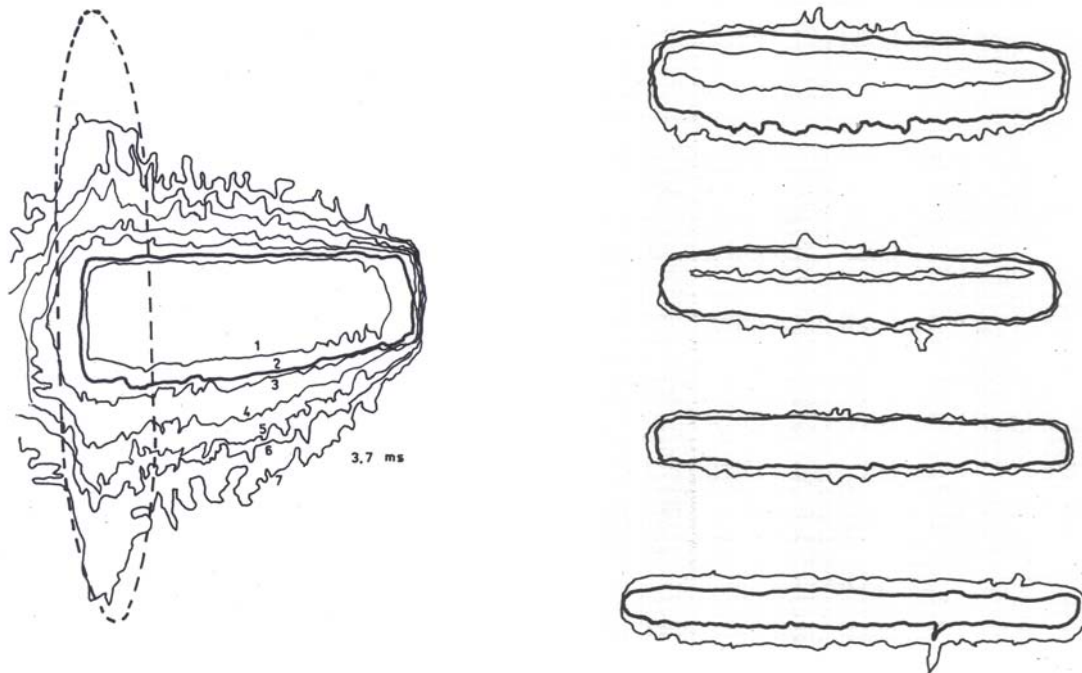


Figure 1. The equidensitometry evaluation of switching arc.

2. NUMERIC SOLUTION OF ELLENBAAS-HELLER EQUATION

The Ellenbaas-Heller equation (energy balance equation in electric arc plasma) is given by

$$\sigma E^2 = -\text{div} \kappa \text{ grad} T \quad (1)$$

where σE^2 is the input electric energy and $-\text{div} \kappa \text{ grad} T$ is the output energy (only heat conduction is taken into account, heat convection and radiation are neglected). σ denotes the electric conductivity, κ the heat conductivity and T the temperature of the plasma. For axially symmetrical plasma the equation (1) simplifies to

$$\sigma E^2 = -\frac{1}{r} \frac{d}{dr} \left(r \kappa \frac{dT}{dr} \right) \quad (2)$$

The solution of equation (2) is simplified by an implementation of the heat flow potential

$$S = \int_0^T \kappa dT \quad (3)$$

By substitution into equation (2) we obtain

$$\sigma E^2 = -\frac{1}{r} \frac{d}{dr} \left(r \frac{dS}{dr} \right) \quad (4)$$

The next simplification is based on a knowledge of the arc plasma diameter which can be determined by the equidensitometry evaluation of switching arc images. Other values necessary for the solution (current and voltage) are obtained from the oscillogram of the switching process.

To solve equation (4), it is necessary to know electric conductivity temperature variation $\sigma = f(T)$ as well. According to its temperature dependency the plasma column is divided in n parts such that in each interval the electric conductivity is a constant. Then by successive integration of (4) we obtain

$$\frac{dS}{dr} = -\frac{r \sigma E^2}{2} + \frac{A}{r} \quad (5)$$

$$S = -\sigma E^2 \frac{r^2}{4} + A \ln r + B \quad (6)$$

The constants of integration A , B are different in particular intervals. Providing that $S(r)$ is smooth functioning the recursion formulas for constants of integration are obtained

$$\begin{aligned} A_1 &= 0 \\ &\cdot \\ &\cdot \end{aligned} \quad (7)$$

$$A_i = A_{i-1} + \frac{E^2}{2} \left[r_i^2 (\sigma_i - \sigma_{i-1}) + r_i^2 (\sigma_i - \sigma_{i-1}) \right]$$

and

$$\begin{aligned}
B_1 &= s_1 \\
&\cdot \\
&\cdot \\
B_i &= B_{i-1} + \frac{E^2}{4} \left[r_i^2 (\sigma_i - \sigma_{i-1}) (1 - 2 \ln r_i) \right]
\end{aligned} \tag{8}$$

The arc current value can be determined from

$$i = \pi E \left[\sigma_0 r_1^2 + \sigma_1 (r_2^2 - r_1^2) + \dots + \sigma_i (r_{i+1}^2 - r_i^2) + \dots + \sigma_{n-1} (r_n^2 - r_{n-1}^2) \right] \tag{9}$$

For the known heat conductivity $\kappa(T)$ the function S can be calculated using the formula (3) as well. Comparing the heat flow potential $S(r)$ obtained from (6) with the function $S(T)$ from (3) the variation $T(r)$ can be determined.

3. DETERMINATION OF RADIAL TEMPERATURE DISTRIBUTION IN AN ARC PLASMA

The goal of the practice training is to determine the radial temperature distribution during the second half of switching process in the extinguishing chamber of SF₆ – high voltage circuit breaker. To solve the problem we have to know the time behavior of voltage and current in the switching arc, the arc length and its radius. It is necessary to know both the electric and heat conductivity of the plasma as well. The current and voltage waveform have been determined from the oscillographs of the switching process. Plasma radius has been obtained by equidensitometry evaluation of switching arc images. The arc length was of 4 cm (maximal distance between the circuit breaker contacts).

The radial temperature distribution for instantaneous current value at given time is calculated using the program EHROVNICEvypocet.m (MATLAB language). The input parameters are as follows: arc radius r_v , arc voltage u_{obl} , and arc length d_{obl} , the initial temperature $tpoc$ (random value, expected temperature in the arc axis). As results of the calculation we can obtain the calculated current value $ivyp$ corresponding to the specific initial temperature and the plots of the radial distribution of the heat potential $S(r)$ and the temperature $T(r)$. Part of the program and the radial distributions are shown in Fig.2 and Fig.3.

Provided the calculated current is consistent with the experimental current value the calculation is terminated and the plot $T(r)$ displays the wanted radial temperature distribution. In other case, the calculation is repeated using the same input values of r_v , u_{obl} , d_{obl} but with new initial temperature $tpoc$ – if the calculated current is less than the experimental value higher $tpoc$ is chosen, for calculated current greater than the experimental value the initial temperature $tpoc$ has to be lower. The calculation is repeated until the match of current values is reached.

```

MATLAB
File Edit View Web Window Help
Current Directory:
Pro vložení vstupních příkazů vlož 1,pro nevložení vlož 0: 1
a =
    1
Vlož vektor vstupních veličin: [rv uobl dobl]: [0.32 2329 4]
vstup =
    1.0e+003 *
    0.0003    2.3290    0.0040
Vlož počáteční teplotu:30000
proud =
    2.145856136444530e+004
Pro vložení vstupních příkazů vlož 1,pro nevložení vlož 0: 0
a =
    0
Vlož počáteční teplotu:25000
proud =
    1.725104873041435e+004
Pro vložení vstupních příkazů vlož 1,pro nevložení vlož 0: 0
a =
    0
Start

```

Figure 2. Part of the program.

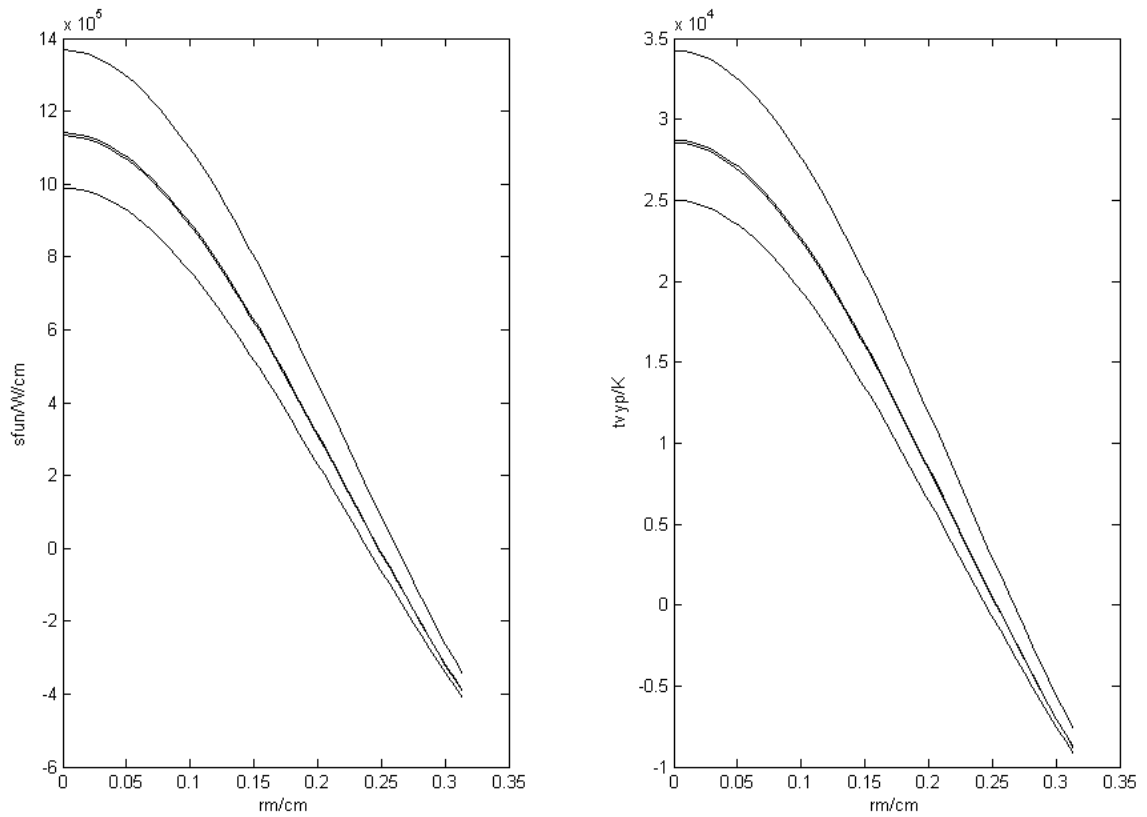


Figure 3. Radial distribution of heat potential and temperature (iterative calculation).

4. CONCLUSION

A computer program for the determination of the temperature radial distribution in electric arc plasma of high voltage circuit breaker has been created. In calculation we use experimental values of arc voltage, current and radius. The program will be used in practice training within the master course Plasma Physics and Diagnostics.

REFERENCES

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