Numerical Study of Thermal Field of Pantograph Contact Strip-Contact Line Wire Assembly

Constantin-Florin OCOLEANU*, Gheorghe MANOLEA**, Grigore CIVIDJIAN*, Cornelia A BULUCEA**
Electrical Apparatus and Technologies*, Electromechanical**
University of Craiova, Faculty of Electrical Engineering*, Faculty of Electromechanical, Industrial Information, Environment Engineering**
Bd. Decebal, no. 107, 200440, Craiova ROMANIA
focoleanu@elth.ucv.ro, ghmanolea@gmail.com, gcividjian@elth.ucv.ro,abulucea@em.ucv.ro

Abstract: - In this paper we performed a numerical study with Finite Element Method (F.E.M.) of thermal field in pantograph contact strip and contact wire. We consider the particular case of heating the pantograph contact strip – contact wire by the electric arc. The pantograph is asymmetric EPC type and the contact line wire is TF 100 type, both used in Romanian Electric Railways. The influence of material parameters on temperature distribution is pointed out.

Keywords: Electric railway, graphite, numerical simulation, F.E.A., thermal conductivity, thermal spectrum.

1 Introduction

The effects of friction and electrical phenomena (electric arcing) govern the wear rate in the sliding contact between pantograph collector strip and contact wire [1].

The formation mechanism of the contact wire wear is complicate. The following shows the main factors having an effect on the progress of contact wear wire [9]:
- pantograph characteristics;
- collected current;
- contact strip characteristics;
- train velocity;
- catenary’s type;
- contact wire surface condition.

With the technology developments of electric railways and the maglev system, speedup of trains and cost reduction of maintenance facilities are strongly required [7]. Major efforts have been devoted to solving these issues and to meeting the expectations. The collector is one of the factors, which can greatly affect the speedup of vehicle and the cost of maintenance.

In [4] the influence of the continuous DC arc whose current values are from 100 A to 400 A on the contact strip of the railway pantograph is experimentally investigated. The results indicate that the DC arc between the contact wire and the contact strip may cause a partial wear of the contact strip, which is a serious problem.

A theoretical and experimental study of thermal stability in graphite contacts (graphite-to-graphite and graphite-to-metal) is described in [10]. It shows that for any given size of contact there is a maximum current which may be passed safely. For currents larger than this critical value no thermal equilibrium is possible, and the temperature rises indefinitely until it is limited by some other phenomenon, or the disintegration of the contact interface due to thermal shock.

When current flows through a contact spot, heat is generated in the constriction resistance and dissipated into the bulk of the conductors. The generation depends on the electrical resistivity, and the dissipation on the thermal conductivity; both of these vary with the local temperature. The equilibrium temperature of the spot reflects the balance between these two processes.

In this paper we performed a numerical study with Finite Element Analysis (F.E.A.) of transient thermal field in pantograph contact strip and contact wire using QuickField Professional, version 5.4.

2 Graphite use as pantograph contact strip

It is well known that the use of carbon materials in pantograph contact strips is an effective way of reducing contact wire wears. A number of railways in Europe use carbon contact strips not only for local but also for high-speed trains [6].

Due to its electrical conductivity, thermal conductivity, oxidation resistance and wear resistance, graphite is used as an electrical contact material, particularly in sliding conditions, as encountered by brushes for electric motors and other devices and by sliding electrical contacts for trams and other electric vehicles [12]. To further improve the conductivity, copper impregnated graphite may be used.

The carbon material which are widely used in Europe have an electrical resistivity values between 7 μΩm and
34 μΩm, and it is desirable to have a value smaller than 3 μΩm to keep temperature rises near the contact point under a certain limit [4].

In [1] is investigated experimentally the influence of friction material on the wear rate of suspension catenary’s contact wire. Contact strips are subject analysis systems used in traction 3 kV DC, copper and graphite. The lowest rate of wear of contact wire is obtained using graphite, while when using the friction of the copper plate to obtain a wear rate up to 6 times higher.

The materials parameters, which influence the temperature, are electrical resistivity, thermal conductivity, specific heat, coefficient of thermal expansion and material density.

Table 1 presents the range parameters values for different graphite types.

<table>
<thead>
<tr>
<th>Specific heat</th>
<th>Thermal conductivity</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{J}{kg \cdot K}$</td>
<td>$\frac{W}{m \cdot K}$</td>
<td>$\frac{g}{cm^3}$</td>
</tr>
<tr>
<td>$710 \div 830$</td>
<td>$5 \div 470$</td>
<td>$1.3 \div 2.3$</td>
</tr>
</tbody>
</table>

Table 1  Graphite parameters values [11]

### 3 Propagation of heat in a field half-space

The analytical model witch give the propagation of heat in a 3D half-space is described below. Figure 1 present the schema for this case.

In (1) $a$ is temperature diffusion coefficient and is given by equation:

$$a = \frac{\lambda}{c \cdot \gamma} \quad (2)$$

Where:
- $\lambda$ is the thermal conductivity;
- $c$ represent the specific heat;
- $\gamma$ is the density.

The temperature distribution equation can be written as:

$$\theta(r, t) = \theta^* \cdot \frac{r_0}{r} \cdot \frac{erfc(z)}{r} \quad (3)$$

Where:
- $z = \frac{r - r_0}{2 \cdot \sqrt{a \cdot t}}$
- $erfc(z) = 1 - erf(z)$

$$2 \cdot \sqrt{\pi \cdot t} \cdot \int e^{-z^2} \cdot dz \quad \text{is the complementary error function.}$$

The heat flux is given by equation (4):

$$q = -\lambda \cdot \pi \cdot r_0^2 \cdot \frac{d\theta}{dr} \bigg|_0 \quad (4)$$

Considering equations (3) and (4) it results:

$$q = 2 \cdot \pi \cdot r_0 \cdot \lambda \cdot \theta^* \left[1 + \frac{r_0}{\sqrt{\pi \cdot a \cdot t}}\right] \quad (5)$$

### 4 Analysis domain and boundary conditions

For solving the problem we used the next boundary condition (fig. 2):
- convection;
- Dirichlet;
- $T = ct.$

The discretization domain and boundary conditions are presented in figure 2. Analysis domain has a mesh with 248000 nods. Figure 3 present a simplifed analysis domain.
The thermal spectrum of contact strip-contact wire assembly due to an electric arc and the influence of thermal conductivity, specific heat and density of graphite, considering the case of contact disk, is studied.

For obtain the thermal field of assembly contact strip – contact line wire we use F.E.M. and solved a transient heat transfer in QuickField Professional, version 5.4.

We considered the particular case of heating the pantograph contact strip – contact wire by the electric arc. In this case we can neglect the electric losses and heat transfer coefficient because the arc temperature is very large (8000 ÷ 20000 °C) and the time is very small, some fractions of second.

As it can be seen from table 1, graphite thermal conductivity varies from $5 \div 470 \frac{W}{m \cdot K}$. Figure 4, 5, 6 shows the influence of thermal conductivity on pantograph strip – contact line wire in the case of large value for heat source in contact zone and for $h_c \neq 0$ ($h_c$ is convection coefficient).

**Fig. 2 Analysis domain and boundary conditions**

**Fig. 3 Simplify analysis domain**

**Fig. 4 Thermal field for $\lambda = 12 \frac{W}{m \cdot K}$**

**Fig. 5 Thermal field for $\lambda = 100 \frac{W}{m \cdot K}$**
Solving the problem for the case of \( a = 78 \text{ mm}^2/\text{s} \) (\( a \) is given by relation 2), considering \( h_x = 0 \) and using a simplify analysis domain (fig.3), we obtain temperature variation function of distance (fig.7) and time (fig. 8).

The next figures shows thermal field for a constant value of thermal conductivity but for a variable value of specific heat (for different values of \( a \)). The temperature values are from 2 mm (fig.9) and 4 mm (fig.10) from contact zone.
Using the same algorithm we performed an analysis by making in evidence the influence of graphite density on thermal spectrum (fig.11).

Fig.11 Temperature at 4 mm distance from contact zone for different density values

6 Conclusion

The thermal conductivity, the specific heat and the density of graphite vary for different pantograph contact strips. It is desirable to have an optimal value of these parameters to keep the temperature rises near the contact point under a certain limit.

The influence of graphite parameters on temperature distribution near the contact zone is evident (fig.9, fig.10 and fig.11).

The propagation of thermal field can be solved theoretically using eq. (3), i.e. considering the model of contact disk.

We solving the problem numerical with F.E.M. and considering the model of contact disk but it can be seen from simulations (fig.4, fig.5 and fig.6) that the surfaces thermal field are almost cylindrical. So, in contact zone can be used, enough well, a cylindrical model to study the thermal field.

References: