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# Thermal analysis of a traction system with double conducting points in steady state conditions

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ABSTRACT

This paper describes a thermal model of electric contacts with double conducting surfaces in electric rails system. The model has been validated for two electric contacts with different contact resistances. The contacts are connected in parallel on the same line contact. First, some experimental tests have been done in order to obtain the contact resistance variation against contact force. Aiming to use the experimental data related to the contact resistances into the mathematical model, the contact resistances' curves have been fitted using a known expression. The obtained mathematical model can be used to analyse the thermal behaviour of electric contacts system in steady-state conditions at different values of the electric current, contact force, line cross-section, distance between contacts, ambient temperature. Also, the thermal model allows the computation of the temperature at different ratio between the currents which flow through electric contacts and different ratio between forces on electric contacts. There is a good correlation between computations and experimental results.



## 1. Introduction

Thermal aspects of electrical contacts are to be found in almost every contact between two surfaces. Understanding the behaviour of electrical contacts under various operating conditions can provide new insights into the contacts' behaviour. Many authors have developed different contact models taking into account the thermal aspects, the contact resistance and the real contact area between the surfaces. The thermal analyses of electrical contacts for different applications are also included. In [1] it is presented an analytical model for predicting the thermal contact resistance of non-conforming rough contacts of bare solids in a vacuum. Fieberg and Kneer [2] analyse the prediction and optimization of the thermal behaviour of combustion engines where the knowledge about the contact heat transfer is important. Shojaefard et al. [3] presents a method for an exhaust valve temperature estimation considering the heat transfer coefficient of the contact surface and estimating the temperature transfer function. A special domain is represented by the contact between the pantograph and the contact line for the electric vehicles supplied from a catenary system, where the contact is realized between two different materials, usually copper for the contact line and graphite for the pantograph strip. In some situations the pantograph–catenary system can be affected by electrical faults [4]. In [5] there are presented aspects regarding the influence of the temperature on the contact line and on the electric current collecting process of the pantograph. Some applications regard the wear of the sliding electrical contacts in motors and generators which is affected by many factors, such as contact force, contact temperature, materials and electrical and thermal properties [6]. The contact resistance is also largely studied in [7], considering the interface of an electrical contact, either stationary or dynamic, as a complex environment because of different physical phenomena which can occur simultaneously at different scales of observations. In order to estimate the contact heat transfer coefficient and the thermal contact resistance, in [8] are used an infrared measurements of the contact bodies and then the reverse problem with conjugate gradient method is solved. Estimating the dependence between the electrical contact resistance and the pressure and temperature is important also in spot welding [9] where using information about the temperature dependence of resistivity and mechanical properties, a curve fitting procedure was used to establish the desired relationship of contact resistance to pressure and temperature. Modelling the contact between two materials and solving the coupled electrical and thermal problem, one can determine the optimal geometry of the contacts for an imposed limit value of temperature [10]. Important applications of the electrical contacts are the automotive connectors, when a current passes through them, the temperature in the contact area being a significant parameter to indicate the damage level [11]. Though it is very difficult to simulate the exact conditions of the automobile connectors, it is possible to study the effect of certain conditions and to correlate their influence on the extent of temperature variation

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**Nomenclature**

| | |
|---|---|
| $F$ | contact force |
| $I$ | electric current through the contact |
| $R_c$ | contact resistance |
| $S$ | line cross-section |
| $l_p$ | perimeter of the line cross-section |
| $j$ | current density |
| $\rho$ | electrical resistivity |
| $\lambda$ | thermal conductivity |
| $k$ | convection coefficient |
| $\theta$ | temperature |
| $\theta_a$ | ambient temperature |
| $\alpha_R$ | coefficient of electrical resistivity variation with temperature |
| $m$ | by definition $m = \frac{l_p k}{\lambda S} - \frac{\alpha_R \rho_0 j^2}{\lambda}$ |
| $n$ | by definition $n = \frac{\rho_0 j^2}{\lambda}$ |

and to predict the reliability of connectors. The temperature distribution in switches and relays is important in order to estimate the thermal interaction among the components and to calculate the interface thermal resistance, even in complex three-dimensional analysis [12]. Different materials for the contacts are also studied as in [13,14]. A wide perspective on researches on thermal contact resistance is presented in [15]. Modelling and simulating the thermal contact resistance involves several aspects, including surface topography descriptions, the mechanical deformation and the thermal models of two solid contact surfaces. Considering the thermal aspects and the contact resistance, it is important that busbar joints estimate the joint resistance depending on the variation of the normal force, varying from the force approaching zero Newton to the maximum force, also to decrease and then increase the force [16]. In [17] there is presented an analysis of the behaviour in electrical contacts, where electrical, thermal and mechanical fields are coupled. The models were implemented in the Finite Element code FEAP considering the pressure dependence of the current flow across the contacts and the heat on the contact zone.

This paper describes a thermal model for an electric traction system with double conducting points. The thermal behaviour of the electric contact system is analysed in the case of steady-state conditions. It was considered different contact forces for each electric contact.

## 2. Thermal model

This study proposes a mathematical model for two different electric contacts connected in parallel on the same line contact, Fig. 1. The current which flows through both electric contacts, has two different values $I_1$ and $I_2$. The sum of these two currents is:

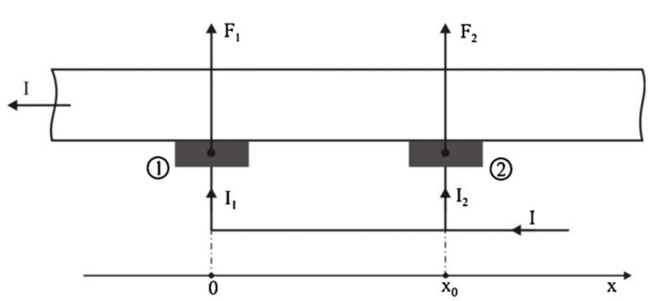


**Fig. 1.** Simplified illustration of the two different electric contacts (1 and 2) connected in parallel on the same line contact.

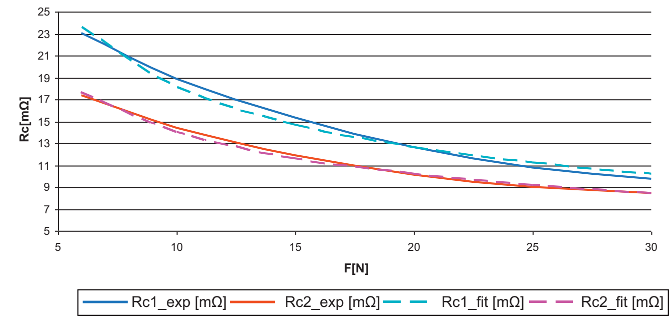


**Fig. 2.** The contact resistance variation against contact force. Comparison between experimental values (Rc1_exp, Rc2_exp) and fitted curves (Rc1_fit, Rc2_fit).

$I = I_1 + I_2$, and the ratio between them is: $I_1 = \varepsilon I_2$, where $0 < \varepsilon < 1$. Also, the contact forces on these two electric contacts, are different, $F_1$ and $F_2$, having the sum: $F = F_1 + F_2$. The ratio between these forces is: $F_1 = \sigma F_2$, where $0 < \sigma < 1$. It results that the power losses on the electric contacts have different values mainly because of different contact resistances. Some experimental tests have been performed in order to obtain the contact resistance variation against contact force for both different contacts. The diagrams are presented in Fig. 2. Aiming to use the experimental results related to the contact resistances in the mathematical model of heating distribution, the contact resistances' curves have been fitted to the following expression:

$$R_{c1} = u_1 F_1^{-v_1} + w_1 F_1^{-1}, \quad R_{c2} = u_2 F_2^{-v_2} + w_2 F_2^{-1} \tag{1}$$

There are a series of known points ($F_k$, $R_{ck}$), contact resistance $R_{ck}$ at certain contact force values $F_k$, established from experimental tests. The approximation function $R_c(F, u, v, w)$ for the contact resistance depends on the coefficients $u$, $v$ and $w$, which can be obtained using the standard deviation $\varphi$, defined by the relation,

$$\varphi = \sum_{k=1}^{m} [R_c(F_k, \quad u, v, w) - R_{ck}]^2 \tag{2}$$

It has a minimum value for the coefficients $u$, $v$ and $w$, which turns the partial derivatives to zero,

$$\begin{aligned} \frac{\partial \varphi}{\partial u} &= 2\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]\frac{\partial}{\partial u}R_c(F_k, u, v, w) = 0 \\ \frac{\partial \varphi}{\partial v} &= 2\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]\frac{\partial}{\partial v}R_c(F_k, u, v, w) = 0 \\ \frac{\partial \varphi}{\partial w} &= 2\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]\frac{\partial}{\partial w}R_c(F_k, u, v, w) = 0 \end{aligned} \tag{3}$$

Taking into account Eq. (1) the following system results,

$$\begin{aligned} &\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]F_k^{-v} = 0, \\ &\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]uF_k^{-v} \ln F_k = 0, \\ &\sum_{k=1}^{m}[R_c(F_k, u, v, w) - R_{ck}]F_k^{-1} = 0, \end{aligned} \tag{4}$$

Solving the above equations system for $m = 29$ points ($F_k$, $R_{ck}$), the coefficients of the fitting curves have been computed: $u_1 = 0.0595$; $v_1 = 0.51752$; $w_1 = 1.67 \times 10^{-5}$ and $u_2 = 0.03977$; $v_2 = 0.454$; $w_2 = 1.35 \times 10^{-5}$. A good correlation between experimental and computed results can be noticed in Fig. 2.