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Abstract of Phd. Thesis

Contributions to the operating system study of contact line pantograph assembly of electric locomotives structure

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Summary

Introduction

Topicality and necessity theme

The vast majority of rail networks need an electric locomotive electric power is transmitted through overhead catenary – pantograph system. One of the most important features of this system is the quality of electrical contact. Running electric locomotives should ideally be made with low contact force to minimize contact wear and destruction of evidence and no power loss.

Pantograph - contact wire contact is a major operation of electric traction vehicles. Through this contact, contact strip on a round wire, so very small contact area, is supplying locomotive engines, which together have an excess of thousands of kilowatts of power.

As speeds increase walking becomes irregular, producing real separation resulting in arcs and increase contact resistance. In estimating the contact wire and contact strip wear of the pantograph should be considered and take into account the electrical resistance dependence of contact pressure. A pantograph - contact wire contact thermal analysis can help improve maintenance operations of all the overheating.

Damage of contact strip leads to hanging contact wire with negative consequences for traffic in electric traction systems. The necessity theme is required by the growing trend in our country the travel speeds of electric trains. It attempts to exemplify the new rail test ring from Făurei establishing a new high-speed rail in Romania.

Problem proposed to solve

Problem proposed to solve is linked to overall warming pantograph-contact wire assembly and has two components:

- developing a mathematical model and a physical model to study electrical contact resistance of the pantograph - contact wire assembly;
- formulation coupled thermal field - electromagnetic field problem to study the thermal field of pantograph - contact wire assembly and numerical solution.

Thesis objectives

Thesis objectives proposed to tackle the problem but also create conditions for further theoretical and applied research in this area:

- determining contact resistance dependence of pressure on the pantograph - contact wire;
- 2D model development and problem solving of coupled thermal - electromagnetic field;
- 2D model development for transitory thermal regime analysis of pantograph – contact wire;
- 3D model development for stationary thermal regime analysis of contact wire;
- study of skin effect influence on contact wire heating;
- determine the structure and principle of an assembly for experimental study of pantograph - contact wire.

Doctoral research methodology

Methodological and theoretical support to carry out scientific research was the consultation of theses, books, technical publications area of prestigious journals and scientific papers, patents, websites.

Based on theoretical model of contact between two flat surfaces, considering normal distribution and spherical asperities, theoretical values were determined for material coefficients *c* and *m* for graphite contact strips. It was created an experimental model for studying contact electric resistance of the pantograph – contact wire assembly and for determining the material parameters *c* and *m*.

It was determining the asperity height distributions with *Kolmogorov*, *Fischer–Snedecor* and *Student* tests. For numerical study of contact wire heating in alternative current, was created a 2D model and proposes to solve a coupled problem electromagnetic field – thermal field.

The used mathematical problem has two components – electromagnetical model and thermal model coupling through source therm.

It was experimentaly determinated the variation law with temperature of heat transfer coefficient for contact wire. Determination was made with experimental results obtained from heating contact wire in alternative current and with minimizes function in technical computing program Mathcad. The obtained law was validated with 2D and 3D numerical simulations.

Thermal field of pantograph – contact wire assembly and the material parameters influence were studied considering the cases of contact disc and electric arc. To study the thermal field of contact wire was created a 3D model. The numerical simulations results were obtained using for heat transfer coefficient the determined law and for source term the obtained values from 2D solving problem. The numerical results were compared with experimental results for calculating relative erors.

The skin effect influence on contact wire heating was study with numerical simulations and experimental determinations. The numerical results obtained by solving a coupled problem were compared to the experimental ones for 201 A and 301 A.

The analysis test systems constructive solutions presented in the international technical literature were established structure and principle of the proposed test ring for experimental study of the pantograph - contact wire assembly.

Scientific novelty of the results

Experimental values obtained for the exponent *m* of the dependence relation of contact resistance with contact pressure on the graphite contact strip – contact wire contact showed that they are much smaller than the theoretical values, in this case can be considered in the research field, that the contact surface is cylindrical and working on a plastic deformation.

Experimental determination of contact resistance dependence with pressure on the three graphite contact strips with different degree of wear, allowed establishing the contact resistance variation and the exponent *m* with the degree of wear.

It was demonstrated that for used graphite contact strips the asperities repartitions can be considered normal and for contact strips less wear exponential repartition. For these demonstration were used the statistical values obtained from roughness diagram and was determined the asperities repartitions using *Kolmogorov*, *Fischer – Snedecor* and *Student* tests.

It was demonstrated that for alternative electrical current values under 300 A, the heat transfer coefficient law can be use with minimal erors.

The 2D model obtained by solving a coupled problem electromagnetic field – thermal field, has two components: electromagmetical model and thermal model, coupled by source therm. It was demonstrated using numerical and experimental results that contact wire heating is influenced by skin effect.

The numerical results obtained on pantograph – contact wire transitory thermal regime shown that thermal field surfaces are almost cylindrical, so it can be use with a good approximation the cylindrical model.

Applied value of work

Obtained theoretical results were aplied in experimental part of the thesis and will be used also in further research as:

- having in view the experimentally determined exponent *m*, can be considered in the research area, that real contact area is cylindrical and working with plastic deformation;
- to study electrical contact resistance of the pantograph - contact wire assembly can be considered that for used graphite contact strips the asperities repartitions can be considered normal and for contact strips less wear exponential repartition;
- physical model of the pantograph - contact wire assembly used to study the contact resistance variation with pressure on the three graphite contact strips with different degrees of wear, it will be used for further research on the influence of contact strip composition on the contact resistance;
- for numerical study of thermal regime coresponding to contact wire in alternative current can be use with minimal erors determined heat transfer coefficient law;

- mathematical model and 2D model coresponding to coupling problem were used for numerical determination of contact wire heating in alternative current;
- for numerical study of pantograph – contact wire transitory thermal regime is proposed cilindrical model;
- the proposed system for pantograph – contact wire assembly experimental will be used for further research.

Dissemination

Main results were obtained in the thesis of 12 scientific papers, 7 as first author and 5 co-author, 3 research contracts and 2 patent applications, which were presented and discussed at national and international conferences, published in journals or in conference volumes.

Thesis structure

The thesis is divided into six chapters and make contributions to the study of the contact wire – pantograph system. Relationships are presented 104, 111 figures, 26 tables and 126 bibliographic items.

In Chapter I has conducted an analysis in terms of overall constructive suspension catenary - pantograph. There appeared overhead suspension types used on international and national electrical and mechanical conditions imposed. Were identified components of a pantograph, constructive solutions and trends for the high speeds. Were analyzed the contact strips made of different materials and presented the importance of the material used in their construction, given that one can cling to the wire breaking contact and cause serious damage to both the pantograph and catenary.

In Chapter II were analyzed mathematical models presented in the literature for the study of fixed and sliding electrical contacts and presented results of their comparison. Many electrical contact resistance studies involve a uniform distribution corresponding microcontacts models of rough surfaces. In this chapter were made a micro and macro analysis of contact to determine the asperity height distribution.

In **Chapter III** was presented a mathematical model to study the electrical contact resistance. Using the electrical contact resistance was determined material coefficients c and m. Based on diagram were determined roughness height and number of smooth values and statistical values for the three samples. Asperity height distribution was studied using Kolmogorov test. For two of the three probes have been analyzed and verified equal variances and means with Fischer-Snedecor and Student tests.

In **Chapter IV** have studied the stationary and transient thermal regimes proper assembly of contact wire - pantograph. Were carried out 2D and 3D numerical simulations for stationary thermal regime of the contact wire. In this chapter has been studied the influence of skin effect on the heating contact wire, numerically and the transient thermal regime due to the occurrence of arcing and material parameters influence on the contact strip thermal field.

Chapter V contains author experimentally contributions. Has been determined experimentally the contact resistance variation with pressure on the three graphite contact strips with different degree of wear. Using the results of experimental measurements of contact resistance were determined material coefficients c and m. The results were compared with values obtained by theoretical.

It was determined experimentally heat transfer coefficient variation law with temperature for suspension catenary contact wire.

Considering the case of stationary electric locomotive was determined experimentally by measuring the temperature in direct contact and with the camera with thermovision.

National technical literature detailing not constructive solutions of test systems for the study the assembly pantograph - contact wire, which is only reported in doctoral dissertations and other publications. In this chapter is presented a proposal for a constructive variant of the pantograph - contact wire assembly test ring.

Chapter VI present author conclusions and contributions.

Conclusions and contributions

Conclusions regarding overhead catenay – pantograph construction

Pantograph is one of the factors that have a particularly large influence on speed of travel and maintenance costs. The literature values for graphite parameters are different, thermal conductivity, density and specific heat have an important role in the contact strips usage at large electrical current intensity. Wear of contact strip of the pantograph is an extremely important feature since a rupture can hang wire contacts.

Conclusions regarding pantograph – contact wire contact

As increasing speeds walking becomes irregular, causing the lift off giving rise to electric arcs and increase contact resistance. In the estimation of contact wire wear and contact strip of the pantograph must be taken into account the electrical resistance dependence of contact pressure. Electrical contact resistance values are dispersed and difficult to predict despite the simplicity of theoretical formulations.

Conclusions regarding stationary and transitory regime coresponding to pantograph - contact wire assembly

A thermal analysis of pantograph - contact wire contact can help to maintenance operations. Thermal field of the pantograph - contact wire assembly and the influence of material parameters on temperature can be studied using a cylindrical model.

Conclusions regarding the instalations for study the pantograph – contact wire assembly

National technical literature detailing not constructive solutions of test systems for the study the assembly pantograph - contact wire, which is only reported in doctoral dissertations and other publications. Other instalations for which data are available more constructive, were designed only for studying the mechanisms driving the pantographs. It can be concluded that, nationally, there is no professional equipment that can be studied in terms of electric and thermal ensemble pantograph - contact wire.

Methodological contributions

In the doctoral thesis was examined in terms of all the constructive suspension catenary - pantograph. There appeared overhead suspension types used on international and national electrical and mechanical conditions imposed. Were identified components constructive solutions and trends for the high speeds. Were analyzed the contact strips made of different materials and presented the importance of the material used in their construction, given that one can cling to the wire breaking contact and cause serious damage to the pantograph and catenary.

Using the theoretical relations literature has been presented an analysis of micro and macrogeometrical electrical contacts. Have been identified and presented mathematical models used in the literature for the study of fixed and sliding contacts. Were presented the principle of solving a problem and coupled finite element analysis methodology. Was defined the term "coupled problems" and presented a simplified overall structure of field problems. Steps were presented to solve a problem using 2D and 3D finite element method, advantages and disadvantages of different methods of predicting phenomena (experience, analytical calculation and numerical computation). Estimated errors were obtained when heated in alternative current of contact wire, by comparing experimental and numerical (2D and 3D) results. Were presented values of electric current intensity for which errors have acceptable values.

Theoretical contributions

Using the theoretical relations literature has been presented an analysis of micro and macrogeometrical electrical contacts. Have been identified and presented mathematical models used in the literature for the study of fixed and sliding contacts. Were presented results of their comparations. Since electrical contact resistance values are dispersed and difficult to estimate was considered a spherical shape asperity and normal distribution of asperity height and presented a mathematical model to study electrical contact resistance.

Using the values of statistical parameters was evidenced, with graphical representation, the influence of the statistical distribution of contact pressure variation. Based on theoretical model of contact between two flat surfaces, considering normal distribution for asperity height and spherical shape were determined theoretical values of coefficients *c* and *m* for the graphite contact strip. Using 3 graphite probes roughness diagram was obtained. Based on diagram were determined roughness height, number of smooth values and statistical values. Asperrity height distribution was studied using Kolmogorov test. For two of the three probes has been analyzed and verified equal variances and means with Fischer-Snedecor and Student tests. Solving equations 3.17 - 3.21 was obtained random variable λ_n. Using Kolmogorov, Fischer-Snedecor and Student test results it was determined asperity height repartition variation with degree wear.

Experimental contributions

The author has created an experimental model for studying physical contact electric resistance of the pantograph - contact wire assembly. With this model were experimentally determined variation of electrical resistance with contact pressure and the material parameters *c* and *m* for three graphite contact strips. It was experimentally determination contact resistance variation with contact pressure.

It was experimentally determination the law of variation for heat transfer coefficient. Determination consisted of heating the contact wire for different values of alternative current. Numerical simulations using 2D and 3D finite element method validated law.

It was determining contact wire heating with numerical simulations, 2D model and proposed solving a coupled problem. The used mathematical model has two components: electromagmetical model and thermal model, coupled by source therm.

It was studied the influence of skin effect on the heating contact wire, numerically and experimentally. Were obtained the values temperatures of contact wire in alternative and continuous current, 201 A and 301 A. Transient thermal regime and material parameters influence on the contact strip thermal field were studied considering the case of electric arcing.

The author has created a 3D model for stationary thermal regime study of contact wire. Estimated errors were obtained when heated in alternative current of contact wire, by comparing experimental and numerical (2D and 3D) results. Were presented values of electric current intensity for which errors have acceptable values.

Considering the case of stationary electric locomotive was determined experimentally by measuring the temperature in direct contact and with the camera with thermovision.

Contributions regarding the achievement test systems for pantograph – contact wire assembly

National technical literature detailing not constructive solutions of test systems for the study the assembly pantograph - contact wire, which is only reported in doctoral dissertations and other publications. Other instalations for which data are available more constructive, were designed only for studying the mechanisms driving the pantographs. The author has presented a proposal for a constructive variant of the pantograph - contact wire assembly test ring.

Proposed research directions

Given the experimentally determined value for the exponent *m*, the contact can be studied using a model that considers surface cylindrical contact and plastic deformation regime.

The physical model of the pantograph - contact wire assembly was used to study the contact resistance variation with pressure for 3 graphite contact strip with different wear degrees. It will be used for further research on the influence of a strip of friction on the contact resistance.

Can study the thermal stationary contact wire regime with the mathematical model 2D of coupled electromagnetic - thermal field by taking into account the variation of electrical resistivity with temperature.

Transient thermal field of the pantograph - contact wire assembly can be studied using a cylindrical contact model.

The proposed system for experimental study of the pantograph - contact wire assembly can be used for further research.

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