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PREFACE

24^{rth} international scientific conference TRANSPORT MEANS 2020 due to the COVID-19 pandemic in the world, for the first time was organized as a virtual event on 30 September - 02 October, 2020. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

The conference aims to provide a platform for discussion, interactions and exchange between researchers, scientists and engineers.

The reports cover a vide variety of topics related to the most pressing issues of today's transport systems development.

The main areas covered in plenary session and in the sections are: design development, maintenance and exploitation of transport means, implementation of advanced transport technologies, development of defense transport, environmental and social impact, advanced and intelligent transport systems, transport demand management, traffic control, specifics of transport infrastructure, safety and pollution problems, integrated and sustainable transport, modeling and simulation of transport systems and elements.

In the invitations to the conference, sent five months before the conference starts, the instructions how to prepare reports and how to model the manuscripts are provided as well as the deadlines for the reports are indicated.

Those who wish to participate in the conference should send the texts of the reports that meet relevant requirements under indicated deadlines. Each report must include: a short description of the idea or technique being presented, a brief introduction orienting to the importance an uniqueness of the submission, a thorough description of research course and comments on the results.

The submissions are matched to the expertise according to the interests and are forwarded to the selected reviewers.

Scientific Editorial Committee revises, groups the properly prepared reports according to the theme and design the conference programme.

The Proceedings are compendium of selected reports presented at the Conference.

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Prof. V. Ostaševičius

Proceedings of 24th International Scientific Conference. Transport Means 2020.

Modeling the Quality of Current Collection Under the Conditions of a Growing Speed of Rolling Stock

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Abstract

The use of high-speed electric rolling stock necessitates increased requirements for the reliability of its operation. Particular attention should be paid to the interaction of the contact line with current collectors. An important area is the development of tools for modeling the interaction of catenary with current collectors. At present, in some sections of railways, there is a need to increase the speed of trains and adapt the requirements for the design of the contact lines, which allow to the owner of the infrastructure to achieve the correct parameters for dynamic interaction on the pantograph-contact line interface in the point of view of the requirements of Energy TSI. In this work the authors discussed the problem of the equivalenting the contact line during the simulation.
KEY WORDS: *catenary, interaction, pantograph, simulation, equivalenting*

1. Introduction

Authors of the article discussed the problems of modeling of the interaction of the contact line and pantograph and validation of the simulation according to standard PN EN 50318: 2019-02. The questions of improving the design of contact lines and pantographs were discussed from the moment of the emergence of electrified railways. Currently, it is well known that the achievement of optimum quality of current collection in terms of economic feasibility can be achieved only by ensuring uninterrupted contact at the point of contact of the contact line and the pantograph. To date, the issue of minimizing the cost of servicing the infrastructure of electrified railways for the transmission of electricity for traction need remains important and relevant. An important aspect, even at the design stage, is the selection of the optimal parameters of the contact lines and pantographs for specific operating conditions which can be realized by modeling of their interaction.

2. Main Material

Mathematical simulation of the dynamic interaction of pantographs and contact line is an effective tool for the development and improvement of contact line systems. Simulation allows us to study the influence of the parameters of the contact line and current collectors on the quality of the current collection without conducting expensive full-scale experiments. Conceptually mathematical models of contact lines, pantographs and models of their interaction can be divided into analytical and simulation models. But it should be emphasized that any model should be tested for adequacy. Analytical models, in turn, can be divided into models with lumped parameters and distributed ones. The most known models are presented in Table 1.

Table 1

The programs for modeling interaction between overhead contact line and pantograph [18]

Model	Producers
CATMOS	Germany (Balfour Beatty)
SICAT Dynamic	Germany (SIEMENS)
PrOSA / SIMPAC	Germany (HNI Institute at the University of Paderborn + DB Research and Technology Center)
OSCAR	France (SNCF + SDTools)
INPAC	France (Alstom)

The creation of adequate models for the interaction of current collectors and contact line with a high degree of detail of these systems is a complex science-intensive task. In accordance with international experience, it can be most effectively solved with the cooperation of specialists in the subject field (contact lines and current collectors) with specialists in the field of applied mathematics. One example of a model with lumped parameters, which also takes into account dynamic processes, though with a number of assumptions, is a model in which, when determining the trajectory of the pantograph and the tension curve along the run, are generally given the maximum run in the anchor section. It is divided into a number of individual segments. The distributed parameters are replaced by concentrated and reduced to the point of contact. This model does not allow to fully take into account the oscillation processes that occur during the interaction of the pantograph with the contact line, but based on a large number of experimental studies, the accuracy of model prediction was improved by introducing correction coefficients. It is relevant for contact lines designed for speeds up to 160 km/h.

An example of a model with distributed parameters is a model where a contact line is presented as a system with distributed parameters, the catenary wire and the contact wire are replaced by a single wire, which has a total pressure and mass [1]. This conditional wire has an arrow deflection of the real contact wire, and its energy is equal to the potential energy of the contact line. A typical example of the application of the finite element method in modeling problems of interaction of contact lines and pantograph was the method of calculating the interaction on the basis of the modified finite element method [2].

When studying the interaction process of the catenary with current collector, it is especially important to take into account all factors that have a significant and systematic impact on this process. In [3], the authors present the results of using a numerical model, which takes into account the detailed design of the upper part of the current collector. The lower and upper frames of the current collector are represented by one concentrated mass, and the double slide WBL 88, unlike standard models [4], is presented as two separate masses, each of which is connected to the frames by spring-damping connections. The results presented in the work show that the first current collector slide in the runs of the electric rolling stock receives greater mechanical loads (dynamic pressure, shocks) than the second. This corresponds to the results of studies presented in [5, 6]. But the authors of work [4] mentioned that this phenomenon is not thoroughly studied - the model presented in the work does not take into account the possibility rotation of the current collection double slide.

A significant error in comparing the simulation results with the experimental ones is also present in [7]. OSCAR software [8] is a three-dimensional finite element model of the catenary, that interacts with the current collector. The current collector is presented in the form of a three-mass model. The number of current collectors may increase - the model becomes multi-mass. This software is aimed at analyzing the distribution of tension along the contact wire, its aging processes, the interaction of the contact line with the current collector. But it should be noted that the simulation results using the OSCAR software significantly depend on the type of current collector model. To achieve sufficient accuracy of results, it is necessary to conduct a number of complex experimental studies.

Also, insufficient detailing of the catenary elements along the anchor section degrades the quality of modeling its interaction with current collectors. In [9] the basics of development the catenary finite element model and four-mass model of current collector are described, it is a part of software package called CALPE 6.0 and is a modern implementation of PANDA [10].

But it should be noted that despite the software implementation of the developed catenary finite element model and current collector, as well as its use by a separate division of Adif Spanish railway company Renfe, this software does not take into account such parameters as spans of different lengths in the anchor section, number of drops in the span, change the catenary height along the anchor section. The proposed methodology for the study of the catenary dynamic interaction with current collectors in [11] shows that an important factor for rating the catenary interaction with the current collector is the air flow. The catenary is represented as a finite element model, and the current collector - as a multi-mass model. At the same time, different time integration algorithms are used for the catenary and current collector.

Current collection quality assessment

For evaluation, the criteria adopted in world practice are used in accordance with international standards [18,19]:

- IEC 60913. Railway applications - Fixed installations - Electric traction overhead contact lines;
- EN 50119. Railway applications - Fixed installations - Electric traction overhead contact lines;
- EN 50367. Railway applications - Current collection systems - Technical criteria for the interaction between pantograph and overhead line (to achieve free access);
- "TSI Energy". The technical specification for interoperability relating to the energy subsystem of the trans-European high-speed rail system - 2002 and 2008 editions;
- EN 50317. Railway applications - Current collection systems - Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line;
- EN 50318. Railway applications - Current collection systems - Validation of simulation of the dynamic interaction between pantograph and over-head contact line;
- EN 50206-1. Railway applications - Rolling stock - Pantographs: characteristics and tests. Pantographs for main line vehicles. - European Standard, CELENEC, 1999;
- UIC 794. Pantograph-overhead line interaction on the European high-speed network;
- UIC 794-1. Pantograph / overhead line interaction for DC-electrified rail-way lines;
- UIC 799. Characteristics of ac overhead contact systems for high-speed lines worked at speeds of over 200 km/h;
- UIC 799-1. Characteristics of direct-current overhead contact systems for lines worked at speeds of over 160 km/h and up to 250 km/h.

The main criteria for assessing the quality of current collection are based on a statistical analysis of contact force. At present, during simulations, presenting current collectors as 2 and 3 mass models is sufficient [12-17].

Simulation program validation

To ensure an adequate assessment of the catenary operation and current collectors, as well as the possibility of comparing the simulation results with experimental ones, it is mandatory to conduct experimental studies using specialized diagnostic tools and in accordance with PN EN 50318 [17].

To validate the model, the results of the calculation of the dynamic interaction of the reference models of the current collector and contact line with normalized data are compared in accordance with the standard. The reference model of the catenary consists of 10 identical spans 60 m long; The reference model of the current collector is two-mass. Simulation is performed at two speeds of 250 and 300 km / h. Checking the model is carried out on the basis of an analysis of the values of eight parameters characterizing the process of interaction between the current collector and the contact line.

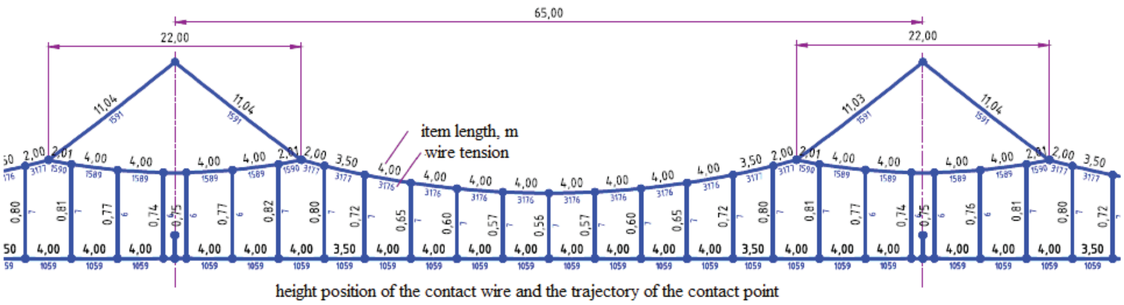
The model validation stage is considered passed only if all parameters fit into the ranges of values normalized by the standard (Table 2) [17]

Table 2

Range of results from reference model

	Range of results	
Speed [km\h]	250	300
F_m [N]	110 to 120	110 to 120
σ [N]	26 to 31	32 to 40
Statistical maximum of contact force [N]	190 to 210	210 to 230
Statistical minimum of contact force [N]	20 to 40	-5 to 20
Actual maximum of contact force [N]	175 to 210	190 to 225
Actual minimum of contact force [N]	50 to 75	30 to 55
Maximum uplift at support [mm]	48 to 55	55 to 65
Percentage of loss of contact [%]	0	0
NOTE The value in the table are based on results from five independent simulation methods. These methods have been checked with results from line tests		

The problem of equivalenting of contact line during simulation



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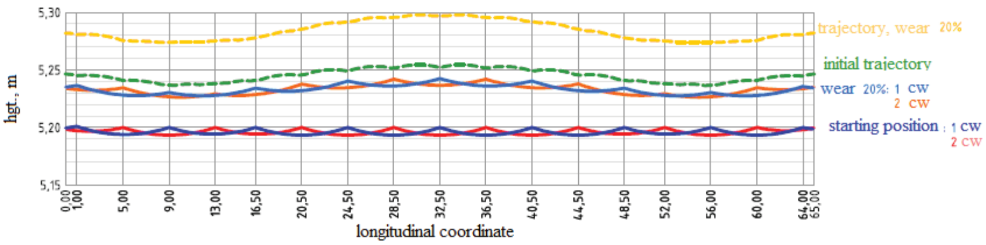

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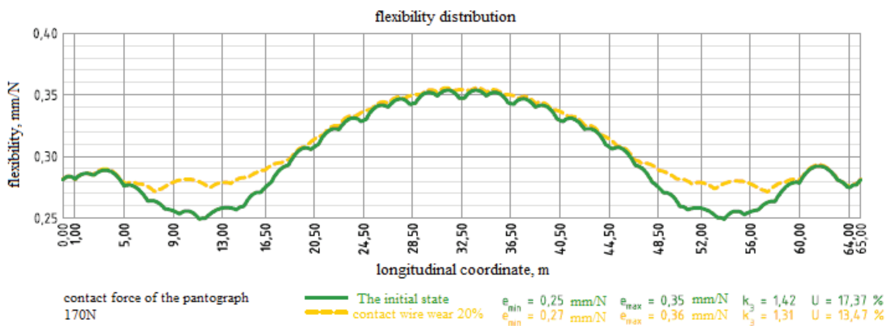

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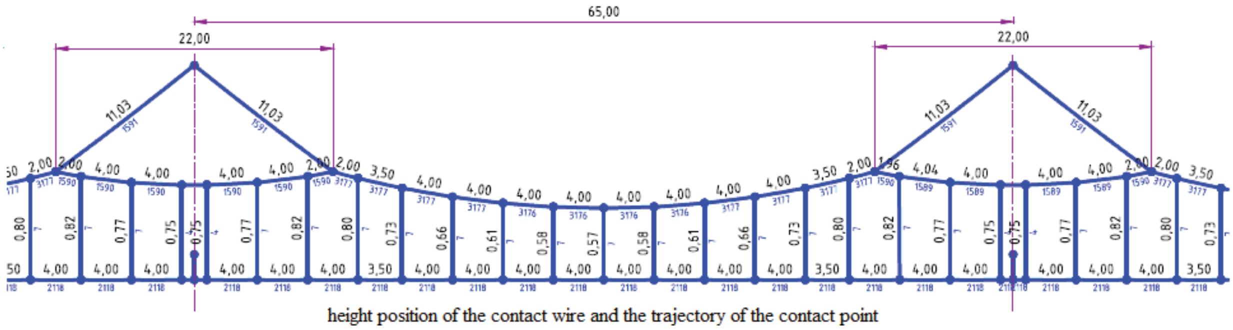
Fig. 1 Static model of the suspension 2C120-2C-3 (curves are shown for constant contact force 170 N) a) the design scheme of the contact line; b) the position of the contact wire in the initial state and with constant contact force (with zero wear and 20% wear); c) flexibility of contact line with zero and 20% wear



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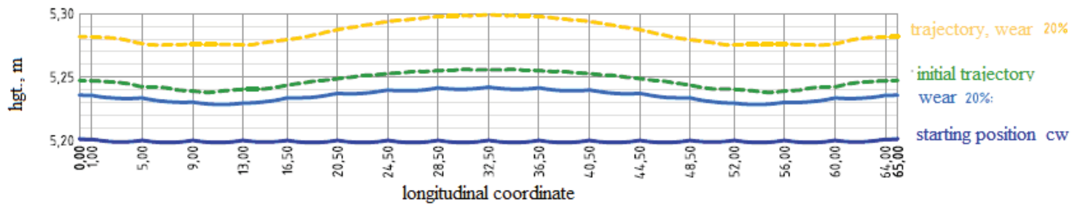

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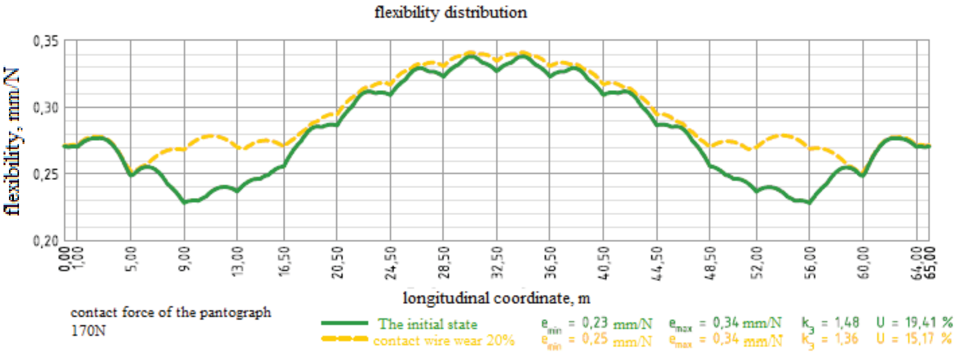

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Fig. 2 Static model of equivalent contact line (curves are shown for constant contact force 170 N); a) the design scheme of the contact line; b) the position of the contact wire in the initial state and with constant contact force (with zero wear and 20% wear); c) flexibility of contact line with zero and 20% wear

At present, in some sections of railways, there is a need to increase the speed of trains and adapt the requirements for the design of the contact lines, which allow the owner of the infrastructure to achieve the correct parameters for dynamic interaction on the pantograph-contact line interface in the point of view of the requirements of Energy TSI. Proposed changes to the contact line parameters that the Contractor will propose to obtain the correct dynamic interaction parameters on the pantograph-contact line interface should be verified by simulation. The presented models and recommendations should take into account the parameters of the contact line based on safety factors in accordance with PN-EN 50119. In addition, it is important in this regard to study the influence of contact wire wearing on a structurally adapted contact line, which allows its operation at high speed, and determine the maximum contact wire wearing, for which the parameters determining the correct dynamic interaction will correspond to the limits given in TSI Energy. At the maximum percentage of wear of the contact wire, it is necessary to take into account the influence of the tension of the wires (if it changes as a result of the recommendation) on their mechanical strength, as well as questions regarding the interaction at the contact point of the pantograph-contact line due to changes in the mass of the contact wires.

Therefore, at the stage of dynamic simulation of the interaction of the contact line and the current collector, the problem of equivalenting the contact line is important. For example, the contact line 2C120-2C-3 [20], which is operated on Polish railways, has a double catenary wire and two contact wires. Below are the results of the equivalentization of this catenary by replacing the contact wires with a single contact equivalent wire and replacing the dual contact wire with an equivalent one wire (Figs. 1-2).

The equivalent error in representing the flexibility of the contact line can be found by the formula:

$$\delta = \frac{1}{N} \cdot \sum_{i=1}^{N} \frac{|e_i - e_{ecvi}|}{e_i} \cdot 100\%, \quad (1)$$

where N is the number of measurements in the simulation; e_i - the flexibility of the original contact line; e_{ecvi} - flexibility of the equivalent contact line.

The calculations by Eq. (1) showed that the equivalent error in the above case varied within 2-10%.

3. Conclusions

Today there are a large number of tools for catenary, current collectors and their interaction modeling, but each of them has limited application. A promising direction in the development of catenary simulation models is the application of the finite element method, and for the modeling of current collectors it is common to use multi-mass models. In operation, there are often problems of increasing the speed of trains on the electrified section. In this case, it is necessary to simulate the dynamic interaction of the contact line and pantographs. It is important to equivalent the real contact line, to replace the double wires with equivalent ones. It has been shown that the error from elasticity equivalentization varies from 2 to 10%, which may be sufficient for simulation without model restructuring procedures (especially if the finite element method is used).

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