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Analysis of measurement uncertainty for contact-less method used to measure the position of catenary contact wire, performed with the use of Monte Carlo method

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ABSTRACT

Currently the majority of main railway lines in Europe are electrified, and electric trains have the biggest share in the entire amount of rail transport. Reliability of electrified railways is closely related to the issue of supplying traction vehicles with energy. The problems connected with diagnostics of energy consumption node, namely the contact line and the current collector, are therefore of fundamental importance for maintaining the high reliability level of electrified rail transport. The paper presents a novel diagnostic method of railway traction catenary using image analysis. Verification of the uncertainty of this method was carried out. For this purpose, a simulation model based on the Monte Carlo method. The influence of measurement uncertainty of input parameters on the accuracy of the method was investigated.

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1. Introduction

The increasing mobility of modern society, as well as liberalisation of business operation principles are generating the increase in the amount of freight and passenger transport, which has been observed in the last few years. This phenomenon constitutes a challenge for the existing transport system, mainly with regard to logistics and organisation. The negative influence of transport systems on the environment, which is particularly visible in the case of road and air transport, is also of considerable importance in the context of transport growth. The European Union authorities, being aware of the increasing problem, attach great importance to the idea of sustainable transport. Rail transport, characterised by high effectiveness, reliability and relatively small impact on the environment, plays an important role in the above idea.

Currently the majority of main railway lines in Europe are electrified, and electric trains have the biggest share in the entire amount of rail transport. Reliability of electrified railways is closely related to the issue of supplying traction vehicles with energy. The problems connected with diagnostics of energy consumption node, namely the contact line and the current collector, are therefore of fundamental importance for maintaining the high reliability level of electrified rail transport. This is why innovative methods, used to define the parameters of contact line and current collectors in terms of project analysis, maintenance research and diagnostic measurements are being elaborated at present. However, it has to be remembered that not only the way of performing the measurement, but also the reliability and plausibility of the achieved results are important. The problem of measurement uncertainty, which is often overlooked in the course of scientific research, is therefore particularly important with regard to the discussed issue, as one has to be aware that sometimes even the advanced measurement methods may prove to be useless in the situation where the level of uncertainty connected with the obtained results was unsatisfactory.

This paper presents the analysis of a contact-less method used for measurement of the position of catenary contact line with regard to the obtained measurement uncertainty. The measurement method has been presented, the influence of individual factors on the uncertainty has been analysed, and the usefulness of the proposed method in terms of metrological reliability has been verified. Elements of the Monte Carlo method have been used for the analysis.

2. Video techniques in measuring and diagnosing contact line and current collector elements

Video techniques are used more and more widely to perform measurements and diagnostics of contact line, to control the coop-

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eration between current collectors and the catenary, as well as to monitor current collectors themselves [1–3]. The measurement of positions of a catenary contact line can be performed in bot contact and contact-less way [3–11]. The contact methods usually involve the use of specially instrumented current collectors. Such a collector is often subjected to supplementary observation with the use of a video camera [4,12,13]. This is why, during the measurement, there is mechanical impact of the current collector on the contact line (uplift), which makes it impossible to perform static measurements. Such measurements can be performed with the use of contact-less methods, where the measurement device, in order to perform the measurement, does not have to interact physically with the measurement subject, in this case with the catenary contact lines. As a rule, contact-less methods require the use of video or laser techniques. Video techniques are also applied in diagnostics of current collector slippers, where 3D laser scanners are usually used [14,15]. Apart from that, research work on using video techniques to detect the moments when the current collector rebounds from the catenary, which is also connected with the occurrence of electric arcs [16,17]. Measuring the degree of contact wire wear is also possible [18–20].

2.1. Contact-less method for measuring the position of catenary contact lines

The contact-less method presented in this paper employs a fast 2D camera and a slotted light source called a "virtual current collector". The idea of this measurement method has been shown in Fig. 1 [21,22].

A vision camera records an image including a spot of light reflected from the surface of contact lines. A special illuminator, emitting a slotted light beam, which looks like a "light curtain" is a source of light. The recorded image is then subjected to advanced computer processing, whose aim is to eliminate unnecessary information, and leave only the above-mentioned image of the light spot. The position of contact line above the track axis is defined based on the way in which the light spot moves within the picture field. This is how the measurement results are obtained.

The geometry of the measurement system has been shown in Fig. 2. Assuming that in the neutral position, i.e. when the contact wire is at a nominal suspension height, and its position is symmetrical in relation to the track axis, the image of the light spot is visible in the centre of the measurement image. Then the dependencies allowing for calculating the measurement results can be shown by the formulae (1) and (2).

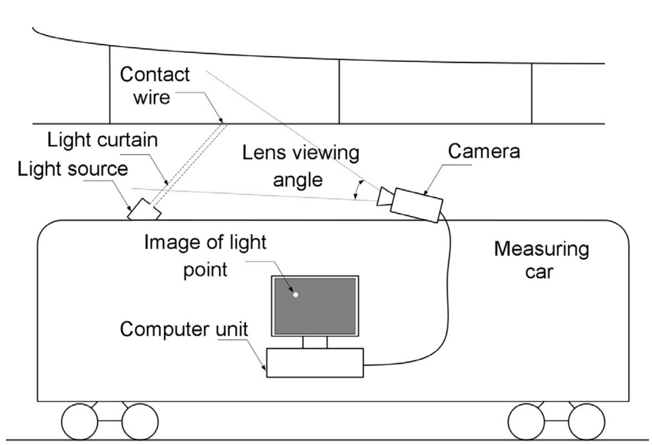

Fig. 1. The idea of contact-less measurement.

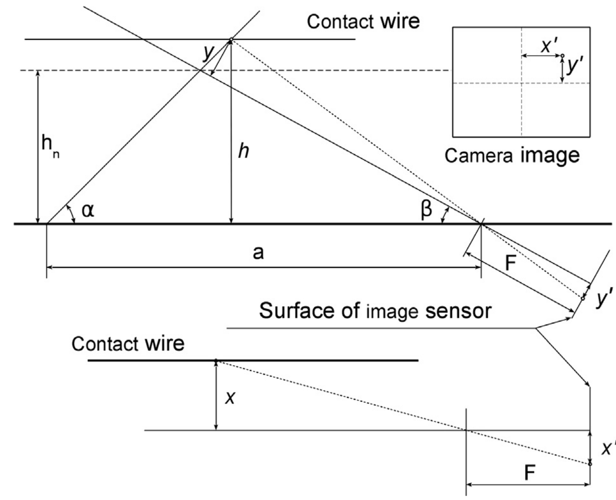

Fig. 2. Geometry of the measurement system.

$$h = \frac{a \cdot \tan\alpha}{1 + \frac{\tan\alpha \cdot \left(1 - \frac{y'}{F} \tan\beta\right)}{\tan\beta + \frac{y'}{F}}} \quad (1)$$

$$x = \frac{\frac{x'}{F} \cdot a \cdot \tan\alpha}{\tan\alpha + \left(\frac{\tan\beta + \frac{y'}{F}}{1 - \frac{y'}{F} \tan\beta}\right)} \quad (2)$$

2.2. The Monte Carlo method

In many cases the solution of a calculation issue is based on an algorithm (a sequence of operations), which allows for finding the searched f value precisely or with a specified error [1]. If $f_1, f_2, \ldots, f_n$ denote the results corresponding to subsequent accumulations of the algorithm operations, then:

$$f = \lim_{n\to\infty} f_n. \quad (3)$$

Due to the finite number of operations, the calculation process is discontinued after a certain number of steps has been achieved. This is a strictly deterministic process: each of the calculation algorithms will result in the obtainment of an identical result [16].

There are problems, for which construction of such an algorithm is very complicated. In such cases the issue is modified, using the laws of large numbers from the probability theory. The $f_1, f_2, \ldots, f_n$ estimates of the searched f variable are obtained based on stochastic analysis connected with the results of certain multiple random samples. In this case the random variable f_n must be stochastically consistent with the searched variable f, i.e. for any $\varepsilon > 0$ there is a dependence:

$$\lim_{n\to\infty} P(|f - f_n| < \varepsilon) = 1, \quad (4)$$

where P means the probability of occurrence of a certain event. The selection of the f variable depends on the character of a given problem. In many cases the searched f variable is regarded as the occurrence of a certain random event. Such calculation process is not deterministic, as it is defined by the results of random samples [16].

The ways of solving issues, where random values are employed, are called the Monte Carlo method. The advantage of this method is the lack of necessity to know the exact dependencies between the data and the searched values. The required knowledge can be restricted to the circumstances in which a given phenomenon occurs.

The core of the Monte Carlo method is repetition of a stochastic experiment called replication, which consists in examining the

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