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Influence of vision measurement system spatial configuration on measurement uncertainty, based on the example of electric traction application

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ABSTRACT

Technical diagnostics plays a significant role in ensuring operational reliability of electrified rail transport. The most critical point in the transmission of electric energy to vehicles is the sliding contact of the current collector with the traction network. For this reason, work is currently being carried on new measuring methods, whose appliance allows for more complete diagnostics of the contact line and current collectors, as well as for monitoring the co-operation of these elements. Each measurement method must be analysed for level of uncertainty, so that the obtained measurement results are reliable. This paper presents a theoretical analysis of the influence of the visual measuring method spatial configuration on the obtained level of measurement uncertainty. This method is designed for measurement contact wire displacements. The results of theoretical analysis were verified by a measurement experiment performed with the use of the Last Square Fitting Algorithm. Finally, the results of sample measurement results obtained at the laboratory tests stand, which proved the practical usefulness of the discussed measurement method, were presented.

1. Introduction

Approximately 900 thousand kilometres of railway lines are currently exploited in the world. Passenger services worldwide reach almost 3.5 billion pkm ($3.5 \cdot 10^{12}$), while cargo services are at the level of 10 billion tkm ($10 \cdot 10^{12}$) and rising. More than 40% of railway lines in the world are electrified. In Europe this index reaches 50%, in Poland 60.5%, while in Switzerland it is 100%. In the case of electrified railway lines damage to the supply system and the contact line results in significant transport difficulties and generates considerable losses. This is the reason why periodical control of technical condition of the overhead contact line (OCL) is necessary, in order to ensure reliability and safety of railway transport systems. In many countries such inspection is performed in a traditional way, i.e. by visual control performed by employees of the infrastructure operator. Such approach is time-consuming, generates breaks in normal functioning of the route and, first and foremost, depends heavily on the subjective assessment of a given inspector. Monitoring the condition of the contact line has been greatly improved by implementing into exploitation diagnostic systems mounted on selected cars and/or vehicles, which can move at the speed allowed for a given railway line [1,2]. The scope of conducted diagnostics includes the so-called static characteristics, i.e. measurement realised without taking into consideration the impact of a current collector on the contact line, as well as the assessment of dynamic quality of the interaction between the two elements for the allowed exploitation velocity. Originally all measurements were performed with the use of so-called measuring current collectors, which introduces certain limitations in the case of assessing static parameters. In order to minimise the influence of dynamic compounds on the measurement, the speed of diagnostic vehicles was reduced. As a result, the time necessary to inspect a given section was visibly shortened when compared to manual inspection; on the other hand, the line capacity was limited. The disadvantages of contact systems are eliminated in contact-less techniques, where an important role is played by visual systems.

There are two main solutions which may be applied in monitoring the technical condition of the contact line. The dominating one is to use a visual system to analyse cooperation between the contact line and a current collector through which the current supplying the vehicle is passing. Such systems can be exploited on vehicles participating in normal traffic, which constitutes their significant advantage. However, in accordance with the provisions of the Technical Specifications for Interoperability and, consistently, in the norm EN-50317, the important factors in assessing the quality of dynamic cooperation OCL-current collector are: the simultaneous measurement of the so-called contact

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force together with the contact wire uplift at the support as the pantograph passes the suspension point or the measurement of the so-called percentage of arcing (NQ). In the case of measuring the NQ either detectors of radiation accompanying arcing [3] or thermovision [4] are applied. Algorithms allowing for automatic detection of light flashes associated with electric arc [5] are proposed with regard to visual systems recording images within the scope of visible radiation. The above-mentioned methods do not allow for detection of arc-free gaps. This is why simultaneous analysis of an image, correlated with analysis of the current taken by a vehicle [6] is often used. In practical system the assessment of quality of dynamic cooperation between the overhead contact line and a current collector is performed more often by way of measuring contact force and the contact wire uplift at the suspension point. Usually the measurement of force is realised with the use of sensor methods, although it is also possible to employ visual techniques [7]. The way of measuring height changes at the suspension point, realised from the vehicle's point of view, has been presented in numerous papers. It is possible to distinguish the methods for dynamic assessment of stagger, described in [8,9] and the solutions appropriate in the light of normative requirements, presented in [10–12].

Systems for measuring static parameters, where the leading role is played by visual systems which do not require the presence of a measuring and/or working collector [13–15] constitute a separate group of solutions. The analysis of applied methods shows that the main focus is on improving the algorithms used for automatic analysis of an image, often recorded in dynamic lighting conditions [16–19]. Within the area of measurements for traction applications, there is no analysis of measurement uncertainty. It is crucial in specific measurement conditions, where the displacement of contact line elements at the level of a few dozen and/or a few hundred millimetres are registered, for safety reasons, from the distance ranging between a few dozen centimetres and/or a few metres. It should be stressed that the measurement resolution usually presented is that which is possible to obtain, while the defined error is either the maximum one, an average one or the RMS one, without any details as to how and with the use of which measurement tools it has been obtained [9,15]. Such approach is useless, as far as metrology is concerned, unless the applied system serves to perform the quality rather than quantity assessment, as has been presented, for example in [5].

The aim of this research is to define measurement uncertainty with regard to the position of an object in motion, with the use of visual technique. It is assumed that the outer dimensions of the object correspond to a typical cross-section of contact wire and that it may move at two degrees of freedom, within the scope corresponding to typical dynamic movements of the contact line, caused by the passing current collector (Fig. 1).

The research was focused on analysing the influence of measurable

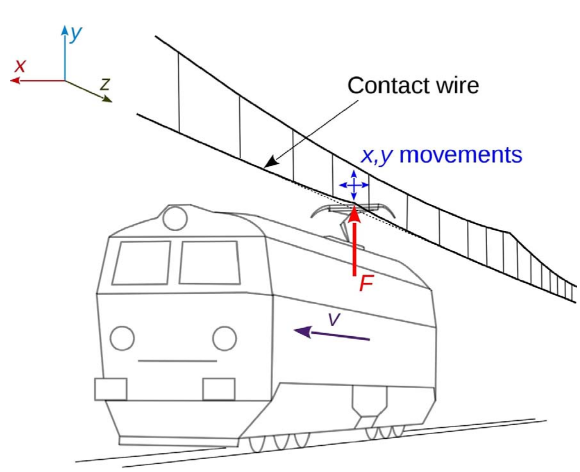

Fig. 1. Dynamic movements of contact wire caused by a passing current collector.

geometric parameters, which unambiguously define the relative position of the camera and the tested object. The proposed new method does not require a calibration procedure; it is only necessary to measure geometrical values at the stage of construction of the measurement system. In particular, such approach is less dependent on external factors, such as significantly different lighting conditions at the calibration in relation to the place where the measurements are performed. Experimental tests have shown that measurement uncertainties obtained with the use of the proposed approach are sufficient for both diagnostic and laboratory measurements.

2. Uncertainty in measuring geometrical parameters with the use of visual methods

The uncertainty in measuring geometrical parameters with the use of visual methods may be generally divided into internal and external, i.e. dependent on and independent of the camera [20]. The factors affecting this type of measurement, which are most often taken into consideration include the following:

(a) Limitations of optics, e.g. distortion or aberration. The deformations caused by distortion have been analysed in literature on numerous occasions. They are usually corrected by introducing a multi-nominal model [21].
(b) Limitations of the bandwidth connected with the time necessary to generate and transmit the image from the camera to the computer [22].
(c) Limitations of algorithms for image transformation, resulting both from the efficiency indicator and from the transformation time [22,23].
(d) Lighting limitations arising mostly from restricted possibilities to ensure constant, clearly defined lighting parameters for the observed scene [24].
(e) Resolution limitations resulting from the applied image converter [22,25].

The above factors are usually not taken into consideration simultaneously. This results from the variety of configurations of the applied visual measurement systems. For the purposes of the conducted research it has been assumed, through ensuring certain parameters at the stage of designing a research stand, that only the influence of spatial configuration and its defined geometric dimensions will be subjected to analysis. There is no comprehensive approach to this kind of analysis in the available literature. In the elaborations [13,14,26] the analysis was performed only for one spatial configuration.

3. Variants of spatial configuration of the system for dynamic measurements of the overhead contact line geometry

The basic requirement for geometrical configuration of a system measuring dynamic displacements of contact line wires by an optical method with the use of a video camera and image analysis is the possibility to record both horizontal and vertical displacements.

Having assumed that the above paramount requirements is fulfilled, the measurement of contact line vibrations may be performed, particularly under field measurement conditions, for two basic geometrical configurations of the measurement system. In the first case, the camera is placed at the same height as the examined element and records the image at a sharp angle in relation to this element of the contact line. The second variant is different from the first one in that the camera is not placed at the height of the examined element, but either above or below it, which makes it necessary to position the camera at a certain angle in relation to the level.

In the course of the analysis, the above variants will be compared with a third, theoretical one, in which the camera would be placed on the axe of the examined element of the contact line (e.g. the contact