Computer Applications in Electrical Engineering

Wear estimation of current collector contact strips by analysis of a 3D scanning results

Leszek Jarzębowicz, Sławomir Judek
Gdańsk University of Technology
80-233 Gdańsk, ul. G. Narutowicza 11/12, e-mail: l.jarzebowicz@ely.pg.gda.pl

The technical condition of current collector contact strips is very important when operational reliability of railway transportation is considered. The authors proposed a novel measurement system based on a 3D camera to register the shape and dimensions of the current collector contact strips surface. The system was installed above the railway track for tests in target ambient. During the trial operation a few dozen of contact strips 3D-profiles were recorded for the locomotives which passed the test point. The collected results vary widely, particularly with regard to the position and tilt of the obtained profiles. This variety makes the surface analysis more complex. Therefore, an automatic method for normalization of the registered profiles was introduced. Standardized profiles are compared with the pattern of a new contact strip in order to estimate their wear. Summary of scanning and analysis results confirm the possibility of commercial use of the introduced system.

KEYWORDS: 3D machine vision, current collector, railway safety, shape measurement, measurement by laser beam

1. Introduction

Uninterrupted current collection by the electric rail vehicles is particularly important where reliability of transportation is concerned [1, 2]. The current collection system consists of the overhead contact wire (or a pair of wires) and current collectors installed on the roof of locomotives and electric multiple units (EMUs) [3]. Faultless current collection is conditioned by suitable construction of the catenary and the current collector but also by their proper maintenance involving regular adjustment, lubrication and replacing worn or damaged parts. Retaining appropriate electrical contact between the current collector and the contact wire is essential in DC current systems, where nominal voltage is relatively low. Therefore, in order to provide vehicles with suitable power, the high current collection capability has to be ensured. For example, in the DC supply system with nominal voltage of 3 kV, the currents may reach 2.5 kA [4]. Requirements for the current collection system increase with the growing speed of trains, due to increasing value of the collected current, as well as the dynamic mechanical interaction between elements of the system.

Current collectors are equipped with a set (usually a pair) of carbon contact strips (Fig. 1), which slides along the contact wire providing the electric contact between the catenary and the moving vehicle [5]. Contact strips wear off due to the friction between the contact wire and their surface. The construction of a catenary ensures unceasing change (stagger) in a position of a contact wire in relation to track axis. As a result, the contact moves across the strip when the vehicle is in motion. Consequently, wear of the contact strip is more uniform. However, the biggest loss of the carbon can usually be noticed in the middle of contact strips (Fig. 1b). Apart from the wear, carbon contact strips are subject to damages such as edge chipping, grooving, detachment of segments.

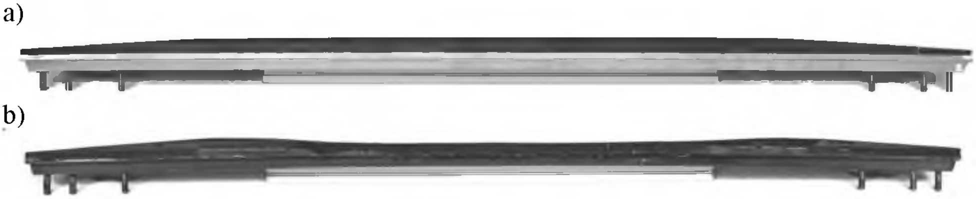


Fig. 1. A new (a) and worn (b) contact strip (approx. width: 1100 mm)

Damage of contact strips or their excessive wear introduces disturbances in current collection process. The electric arc appears which melts the parts of the contact wire and the current collector. Additionally, the damages may result in the occurrence of transverse forces on the contact wire, which cause oscillations or even a break of the catenary.

Inspection of the contact strips takes place during periodical service of locomotives and EMUs performed in the rolling stock depots. The assessment of current collector is usually performed manually. The test stand for scanning and automatic diagnostics of the contact strips, designed for operation on a railway line, was proposed. The measurement takes place when a locomotive passes the scanning point. A 3D camera and a linear laser illuminator have been used for acquisition of data concerning the shape of contact strips surface. A photograph of the stand in presented in Fig. 2. A detailed description of 3D measurement principles and the structure of the system were included in the chapter titled: "*3D scanning system for current collector contact strips*" and in [6, 7].

The trial operation of the scanning system took place on a track leading out of the rolling stock depot in Gdynia. During the operation a few dozen of contact strips 3D images of were registered. The collected results are characterized by a great variety, particularly with regard to the position of the considered contact strip and its tilt, both in the horizontal and vertical planes. As a result, automatic wear analysis is considerably difficult. The algorithms for automatic processing and analysis of the registered results were elaborated, allowing for assessment of the wear of contact strips.

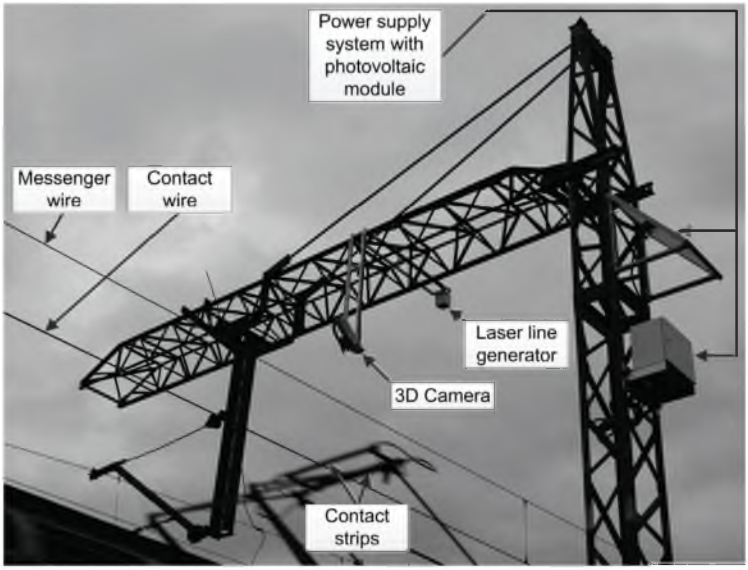


Fig. 2. The 3D-scanning stand during the trial operation

2. Scanning results processing

The 3D camera was subjected to calibration, which took into consideration the relative position of scanned contact strips, the camera and the laser illuminator, as well as the distortions introduced by the camera lens. As a result, the FPGA, which the camera is equipped with, recalculates the registered data in real time. Consequently, numerical results have a form of a height scalled in millimeters, which represents the real dimensions of an object.

Results registered by the 3D camera have a form of an matrix **W**. The number of columns results from the resolution of the camera image sensor. The number of 1536 columns corresponds to the width of the scanned area, i.e. 1172 mm, which translates into the resolution of approximately 0.76 mm/pixel.

The number of lines in the **W** matrix results from the frequency of profile measurement and the recording time. The measurement period was set at 4 ms. This value results from the minimum exposure time of the camera image sensor, which allows for capturing the course of laser line on a scanned object. Due to the fact that it was not possible to establish automatically which of the current collectors on a locomotive is used, the registration covers the time when the entire length of the vehicle roof passes under the scanning point. Because of this, the number of lines in **W** matrix ranges from a few to a dozen or so thousand, whereas the proper data, i.e. profiles of a pair of contact strips mounted on a current collector, are usually contained in no more than two hundred consecutive lines.

With the use of LabVIEW [8], it was possible to elaborate software procedures which automatically locate lines containing the data registered when a current collector passes under the measurement point. A sub-matrix, whose number of lines equals 300, including the profiles of the pair of scanned strips, is cropped from the **W** matrix.

Sample contents of the sub-matrix have been presented graphically in Figure 3. Pixels of the image correspond to the elements of the resulting matrix, and the brightness of the point is dependent on height. Each shade on the 256-level grayscale denotes a change in height by about 0.4 mm. The adopted scale allows for obtaining an image of height changes within the range of approximately 10 cm.

Fig. 3. Graphic presentation of contents of sample matrix resulting from 3D scanning:
1 – contact strips; 2 – horns; 3 – construction elements of the head; 4 – contact wire;
5, 6 – occlusion resulting from messenger wire

Due to differences in assembling the current collectors and the flexible suspension of the head, in the registered images the edges of contact strips are not always parallel to the x axis (see Fig. 3 for method of axis marking). With the aim of unifying the results, the tilt angle of strip edge in relation to the x axis was defined for each case, followed by calculations which reduced that angle to zero. IMAQ library of LabVIEW environment, which includes parameterized edge detection and image rotation algorithms [9], has been used for this purpose.

As a result of asymmetric position of the camera in relation to the track axis, the left edge of contact strips is not visible in the registered image. Only the right edge: k_L, k_H can be seen. Consequently, establishing the middle point of the strips – an important stage in the analysis of scanning results – is possible only by way of determining the inner edges of horns: n_{LL}, n_{LH}, n_{RL}, n_{RH}. Location of the above-mentioned specific points is significantly different in subsequent registration results. Therefore they have to be located separately for each of the matrixes.

Registered profiles of a contact strips are partly shaded by the contact wire and its shadow resulting from occlusion of the laser beam. Additionally, due to the fact that the laser line generator, for safety reasons, had to be placed above the contact line (see Fig. 2), the shadow of the catenary wire is also visible on contact strips. The above-mentioned deficiencies in registered profiles of contact strips limit the possibilities of detecting defects, which may appear along the whole width of the strip. However, taking into consideration the wear analysis, the covered parts of strip profiles do not introduce significant drawbacks. The greatest wear always appears in the middle part of a strip (see Fig. 1b), which touches the contact wire for most of the working time. This area is not shaded in registered images.

4. New contact strip pattern

In order to assess the loss of the contact strip carbon resulting from wear or chipping, it is necessary to know how the surface of a new contact strip is shaped. Results of registration performed for one of the locomotives, in which a pair of contact strips had been replaced with new ones directly before the vehicle passed under the test point, were used in elaboration of a pattern profile. Scanning was performed twice and, as a result, the total of 4 outcomes corresponding to new contact strips was obtained. Those profiles were then averaged, following mutual adjustment of their position and tilt on the *x*-*z* plane (Fig. 4). The averaged profile, which included slight ripples, was subjected to approximation. Due to lack of function describing the profile, and to the complexity of its shape, the pattern was elaborated with the use of the cubic splines.

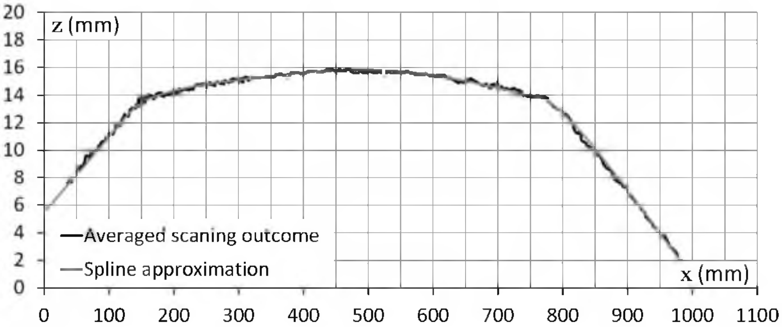


Fig. 4. The pattern determined by processing results of new contact strips scanning

5. Assesment of contact strips wear

Assessment of the wear in the analysed contact strip is performed by comparing its profile with the pattern. However, the registered results are characterised by a great variety, regarding the location and tilt of the scanned profile. To make a reliable comparison with the pattern, the registered profiles have to be normalised automatically by appropriate shift and rotation. The normalization is performed in four stages presented briefly in Figure 5.

The first stage was described in the Ch. 2. Second stage is rotation (leveling). Due to elastic, double-sided suspension of the slipper to which the contact strips are attached, profiles drawn on the *x*-*z* plane are not horizontal in most cases. Although the angle does not exceed 2°, it is advisable to level the profile, due to the considerable length of contact strips (1100 mm) and high resolution of the measurement (approx. 0.1 mm). The difficulty lies in determination of the rotation angle. Examination of a large number of contact strips, exploited in various levels, shows that the wear covers almost the entire length of the strip, apart from a few centimeters at both edges. Reference points, which would simplify profile normalization, could be defined within both these side areas. However, it is not possible, due to the fact that the left edge is not visible in the scanning results (Fig. 3). Therefore it has been assumed that wear of contact strips is symmetrical and two reference points, symmetrical in relation to the center of the strip (within the area subjected to wear) are used to determine the rotation angle.

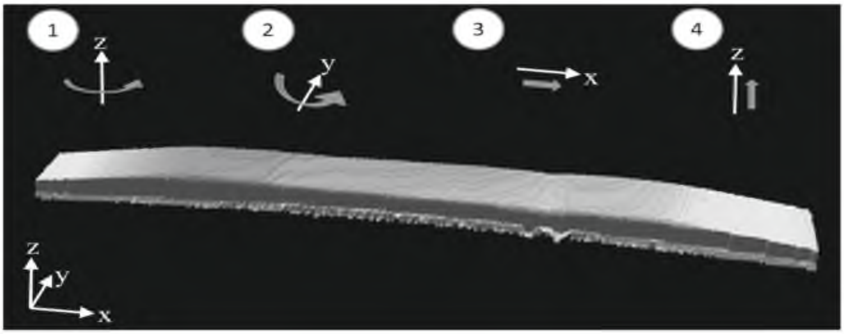


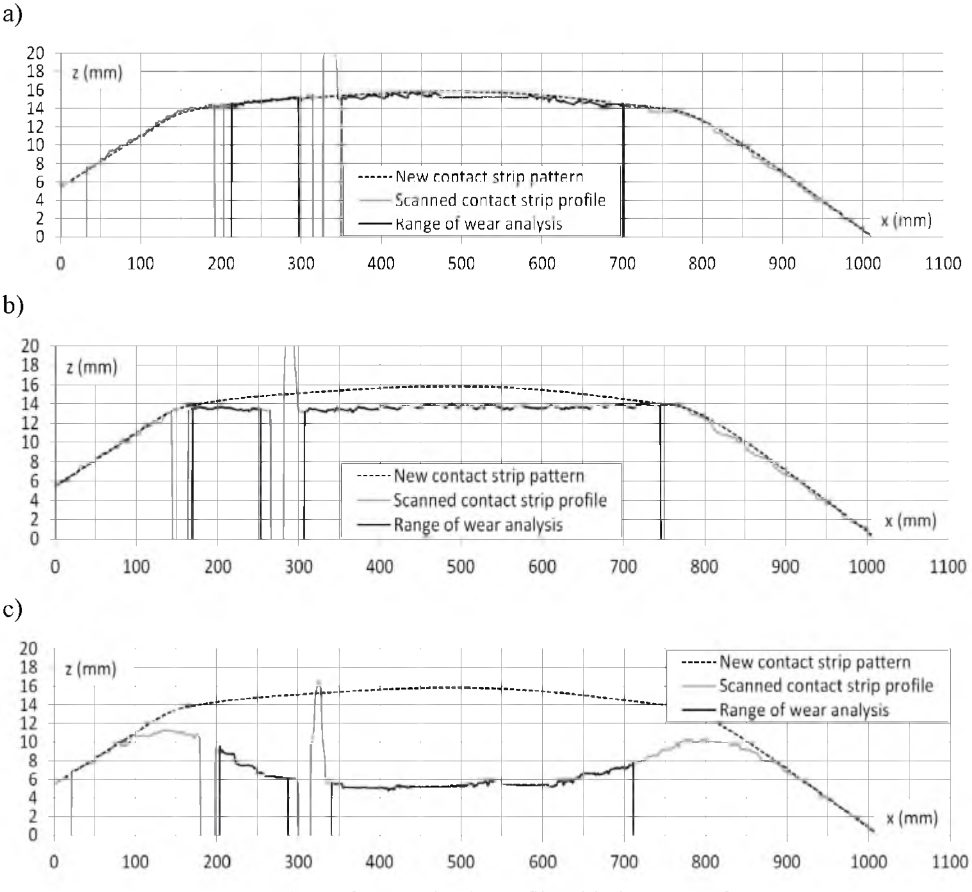
Fig. 5. Subsequent stages of scanning results normalisation

Leveled profiles are next moved along the *x* axis in such a way that their centers correspond to the center of the pattern profile. Centers of profiles are established based on the edges of horns (n_{LD}, n_{LG}, n_{PD}, n_{PG} in Fig. 3).

In order to obtain the comparison with the pattern as precise as possible, it is very important that the analysed profile should be moved along the *z* axis. The reference point which allows for establishing shift values was selected at the right edge of the profile, within the area not subjected to wear. It was considered whether such points should also be defined on the horns which, in principle, are not subjected to wear. In the current collectors for which contact strip profiles were registered, the horns are made of aluminum bars. Repeatability of their profiling is unknown. What is more, such flat sections may become deformed in the course of exploitation. Therefore the above-mentioned idea was abandoned, although it is worth considering with regard to other types of current collector construction.

Comparison of sample normalized profiles of the registered strips with the pattern has been presented in Figure 6.

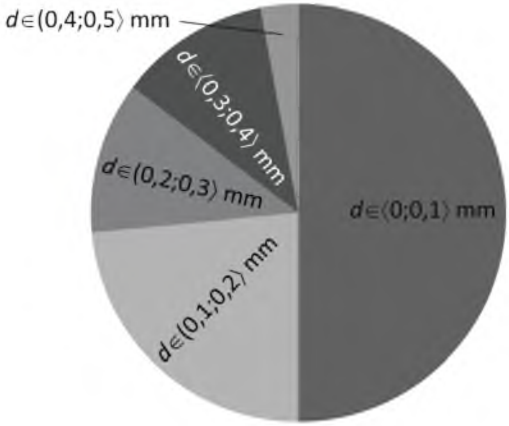
In the analyzed profiles we can observe ranges of *x* values, for which the *z* height is an disturbed value, resulting either from shading of the strip by a contact wire or from the occlusion of the laser line. In the course of automatic analysis two sub-ranges of the analyzed profile are selected. They cover this part of a contact strip which is subjected to the most significant wear. At the same time, they do not include these areas in which height values are disturbed (the selected profile has been marked in Fig. 6 with a bold black line). Assessment of the wear value Z is performed by detecting the biggest difference between the analyzed profile of a scanned strip and the pattern. The Z values, calculated automatically by the algorithm are: $Z_a = 0{,}7$ mm, $Z_b = 2{,}3$ mm, $Z_c = 10{,}8$ mm.



Rys. 6. Comparison of scanned strip profile with the pattern for a new (a) slightly worn strip (b) and significantly worn strip (c)

A few dozen contact strips were scanned in the course of site operation research, and many of those strips were scanned repeatedly. For those cases a repeatability coefficient d was calculated. This coefficient is the difference between the determined maximal and minimal wear of a given contact strip. Value of the *d* coefficient did not exceed 0.5 mm for any of the examined cases and, for half of the strips, did not exceed 0.1 mm (see Fig. 7).

Site research conducted on the railway line confirmed the possibility of using the 3D technology for scanning the surface of contact strips in current collectors with the aim of assessing their wear. A large distance between the camera and the scanned object, partial shading of the strip by elements of the contact line and difficult ambient conditions cannot be regarded as critical factors.



Rys. 7. Distribution of repeatability in determined wear of contact strips

6. Summary

When choosing the place where the measurement system is to be installed, the displacement (stagger) of contact wire and the catenary (in relation to the track axis) has to be taken into consideration. Deficiencies in profiles of scanned contact strips, which are connected with the above-mentioned elements, should not appear in the middle part of the strip, i.e. the area which is subjected to the most extensive wear.

All the registered contact strips were examined and measured manually in the course of usual technical inspection of locomotives, conducted shortly before those vehicles passed under the measurement point. The differences between automatic and manual measurement amount to as much as 2 mm. However, the manual measurement was usually performed in the middle of contact strips, while, due to irregularity of wear and small local damages, the point of the biggest height decrease did not always appear within that area. Hence the results of manual measurement cannot be regarded valid, useful for verifying the precision of the proposed automatic stand. In the course of site research only the repeatability of results obtained through multiple scanning of the same contact strips was assessed. Further research, conducted in laboratory conditions and using carefully dimensioned contact strips (worn to a different degree, as well as damaged ones) will allow for drawing unequivocal conclusions regarding the precision of scanning results and their analysis.

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