Optical remote inspection of live contact-wire cross-sections

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Optical detection of wear and defects in an electro-supply network shows promise for railways and other electrically powered vehicles.

One of many important railroad maintenance tasks is the inspection of the condition of the contact wire that supplies electricity to a train. Over long periods of operation the wire deteriorates, and these changes in its shape must be monitored. But measurement is tricky because the wire is always live, carrying up to several tens of kilovolts. A suitable system must permit evaluation of the height of the wire with a margin of error no greater than 0.2mm, and while the train is moving.

Optical methods have proven useful for many industrial chores, and among the most promising is so-called shadow analysis. However, this approach has the disadvantage that geometric information is lost in obtaining shadows from opaque concave objects. Here we describe a method using structured light (a means of extracting space and depth information) for wire geometry measurement and surface defect inspection.

Consider the principle of measurement for obtaining wire cross-section parameters shown in Figure 1. A special illuminator forms one or several transverse plane-shaped beams that are incident on the wire surface at some angle to its axis. From the other direction (opposite that of illumination) the scattered light is captured using a video camera. The image acquired represents the shape of the curve formed by the intersection of the plane-shaped beam with the curved wire surface.

The scale of the camera image across and along the wire depends on the selected illumination angle (formed by the direction of the illumination beam and the axis of the wire) and the observation angle (formed by the direction of illumination and observation). The actual image of a wire, which we obtained on the system prototype under laboratory conditions, is shown in Figure 2. The thick red polyline demonstrates the predicted wire section profile, which is obtained by processing the light crescent image (the bright green arc-type shape).

The inspection system consists of a measurement module and a station for data accumulation and processing. The former acquires the primary video information, which contains data on the geometrical parameters of the contact wire(s) under inspection. This information is then passed on to be stored in a database and processed. The required parameters are then calculated and transmitted to another database.

The measurement field is ∼1000mm wide (since the wire can move in the horizontal plane) and ∼1500mm deep (due to the possible vertical movement of the wire relative to the rails). We tracked the height of the wire by moving the illumination source while keeping the distance between the source and wire constant. The camera was also kept moving relative to the wire to maintain the distance between the camera and wire constant at 2500mm.

The measurement module contains optical, tracking, and image registration subsystems. The optical subsystem includes a moving laser and two mirrors: one is fixed and the other is mobile to adjust the illumination and observing angle. A 4W, 810nm semiconductor laser was selected as a source of illumination.

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The tracking system consisted of a stepper motor and control software executed on a PC104 microcomputer. Three similar cameras were evenly spaced to extend the field of view in the horizontal plane. This was necessary since the contact wire has large zigzags in the horizontal plane that cannot be covered by single camera. Very narrow bandpass interference filters were used in front of the camera lenses to suppress ambient light. The known radius of curvature of the lower part of the ideal wire makes it possible to compare the unworn shape (shown in Figure 3 in black) with the actual shape (shown in white).

Figure 2. Image of a wire cross-section obtained using the inspection system prototype.

| Wear width | 8.0 mm |
| Wear depth | 1.4 mm |
| Wear remaining height | 10.6 mm |

Figure 3. Image contouring: calculated contour of worn-out wire (solid white line), the supposed contour of the wire (dotted white line), and the expected contour of a healthy wire (black line).

The results of preliminary tests of the system show good agreement between the measured data with the results of the direct measurements. The rms error of the wire height determination did not exceed 0.15mm. During the tests, the speed of the train with the mounted measurement system was 5km/h. The measurement rate is ~150 measurements per second: enabling 10mm steps along the wire length. At the moment the system prototype is under experimental operation on the West-Siberian Railroad (see Figure 4).

Conclusion

Our inspection device measures essential technical wire parameters such as remaining height with rms values down to 0.1mm. Furthermore, the cross-sectional area of the wire can be measured with an rms area noise value of 1.5mm², which is sufficient for confident decision making based on the wire wear and defect search performed by this device. The method could prove useful in automatic wire wear measurement and defect detection for railways, trams, trolleybuses, and similar systems of electrically powered vehicles.

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**References**