Measurement of geometric parameters of extended objects based on the four-coordinate method with a displacement

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Abstract. The paper states that the diameter control in the cable industry is one of the fundamental factors in the final product quality. Such control takes place under the condition that data on the diameter of the electrical insulating sheath of the electric cable will be received continuously. It is possible to evaluate the surface quality of the cable insulation coating, to track thinning, thickening, and some other local surface defects when we receive and process data on the object of control in real time. Modern production facilities are focused on resource efficiency. It means that reducing the consumption of expensive cable materials (non-ferrous metals, alloys, glass, polymers) and insulating materials (plastic compounds, PVC, rubber, etc.) will be one of the main factors in setting up a production complex. The continuous control of the diameter has the ability to provide for such a factor, and also makes it possible to automate the adjustment of the diameter as well as the thickness of the insulation coating using the meter as a part of automatic control systems.

1. Relative work

Nowadays, optical control methods are widely used in the cable industry. The reason is the speed of measurements, insignificant error, and resistance to noise. All data are obtained thanks to non-contact measurement methods, and the use of optoelectric devices [5]. They use coded optical scales, interference methods, amplitude and pulse modulation. Point emitters, microcontrollers, microelectronics and photodetectors are on their basis.

There exist five main methods of cable quality control:

- direct-shadow parallel light method;
- direct-shadow divergent light method;
- radiation power measurement method;
- scanning measurement method;
- optical method for measuring thickness.

All these methods guarantee high measurement accuracy. Various types of equipment, schemes and works are used for their implementation.

1.1. Direct-shadow parallel light method

This measurement method is widely used today. It is applied to estimate a diameter. The measuring range varies from 1 to 35 mm. Unlike other methods, it does not involve any moving devices [2].
A point emitter (in this method, an incandescent lamp, a light-emitting diode or a semiconductor laser module is used), creates a parallel beam of light in the operating area using a collimator. A wire moves horizontally through this area, casting a shadow on the multi-element photodetector. The photodetector consists of cells [10].

The wire diameter is calculated using the formula:

\[ D = n \times l, \]  

(1)

where \( n \) is number of shaded cells, \( l \) is their length (range from 1.5 to 60 μm).

The main error in this method is not an ideal system of the optical collimator. The impossibility to create a completely parallel beam of light leads to inaccuracies in the work area.

Direct-shadow divergent light method.

The operation technique is similar to the direct-shadow parallel light method. The main difference is the absence of a collimator that converts a point light source into a parallel one. This method uses two-point light sources (semiconductor lasers). They create a diverging beam of rays incident on the photodetector array [1].

The operation technique is presented in figure 1. \( S_{x0} \) and \( S_{y0} \) are light sources. X-axis and Y-axis are two measuring channels perpendicular to each other, \( B_{x0} \) and \( B_{y0} \) are initial coordinates. When the cable moves in the measurement area, its size starts changing, respectively, and the size of the cast shadow along the X and Y axes changes. These changes are recorded by the microcontroller, and on the basis of these data, the actual cable diameter is calculated [2].

1.2. Radiation power measurement method

The description of this method is as follows. The cable is placed into the operating area between the photodetector and the emitter. A parallel light beam emitted by the emitter passes through the operating area. The radiation power becomes lower passing through the cable. The difference between the initial and final flow is recorded by the receiver. After that, the change in power is converted into the cable diameter [4].

It is necessary to have a transmitter to obtain accurate data with this method whose power does not change over time. Also, it is necessary to have a receiver whose sensitivity is constant. It is very difficult to comply with these factors in real conditions, Therefore, in this case a rather large error is obtained [6].

1.3. Scanning method of measurement

The light source is laser; a hexagonal mirror is installed in front it. Such a construction creates a thin beam rotating at a speed \( V \) in the operating area of length \( W \). The beam is broken passing through the...
cable placed in the working area. The moving time \( t \), during which the beam passes through the cross-section of the cable, is fixed by a photodetector. Further, the cable diameter is calculated by the formula:

\[
D = L \times W,
\]

where \( D \) is a wire diameter, \( W \) is a length of the working area. The characteristic \( L \) is calculated as follows:

\[
L = \frac{t}{T},
\]

where \( t \) is the time of passing a beam through the cross-section of the cable, \( T \) is an entire scanning period of the operating zone [2].

1.4. Optical method for measuring thickness.
A special device, an extruder, is used for this method. This device is used for manufacturing products from plastic and bulk materials [7].

The operation technique of this method is as follows. The first piece of cable with a diameter \( D_1 \) is installed in front of the extruder. The diameter of the wire with \( D_2 \) insulation is fixed passing through the apparatus. The final cable diameter is calculated according to the formula:

\[
\frac{(D_1 - D_2)}{2}
\]

Also, there exists another method connected with the use of optical devices.

1.5 Inductive optical method for measuring eccentricity.
The calculations are made on the basis of the difference determination between the positions of the optical center of the wire and the center of the core. The optical center is found applying a two-dimensional optical system. An inductive sensor determines the center of the core [11]. The scheme of this method is presented below:

![Figure 2. Measurement scheme.](image)

Here \( w_{21} \) and \( w_{22} \) are the measuring sections of the windings, \( w_1 \) is the current-carrying conductor (it creates induction in the operating area), \( LS \) is a light source, \( IN \) is an inductor, \( FD \) is a photodetector.

The wire passes through the ring of the inductor. An alternating current is passed along the circuit. Due to this, an alternating current is also created in the wire core, which generates a magnetic field.
around it. The electromotive force appears in two measurement sections. The total electromotive force of the measuring windings is associated with a change in the position of the conductor (cable) along two orthogonal axes [11]. Thus, it is possible to get information about the displacement of the cable conductor relative to the axis along which it lies. And the information on the displacement of the cable sheath is obtained on the basis of the direct-shadow divergent light method. For this, radiation sources are placed on opposite sides of the cable. The eccentricity value is calculated by subtracting the vector of the transverse displacement of the axes of the core and the cable sheath relative to the axis of symmetry of the transducer [13].

2. Building models of optical circuits of meters with a different number of measurement axes
In the course of the research work, it was decided to build schematic models of diameter meters. This direction of work was chosen to compare possible errors in the measurement process, as well as to simulate circuits with the smallest number of measuring axes and at the same time with the highest accuracy.

Seven optical measurement schemes were considered and modeled: 1, 2, 3, 4, 6 coordinates and photodetector rulers, respectively. Separately, modeling and research of a 4-axis meter with two photodetector rulers was carried out.

![Figure 3. Optical measurement scheme for 1, 2 and 3 coordinates.](image)

In the course of modeling the measurement schemes, it was possible to make a decision that the practical application of a one-coordinate scheme of an optical diameter meter in a diverging light beam was unreasonable due to the extremely low measurement accuracy (the size of a hypothetical defect can many times exceed the diameter of the controlled object). However, some circuits and devices based on a one-coordinate measurement method in a quasi-parallel beam are also known.

The technological capabilities help to create only closed ring-shaped stationary measuring systems starting from the 6-axis control method. Also, the price of such devices increases significantly, due to the high complexity of the construction. This imposes some restrictions on the range of controlled products, and, as a consequence, enterprises often prefer more adaptive systems, such as 2, 3 and 4-axis.

The models of a 4-axis meter with two photodetector lines are given below. These schemes are notable for their resource efficiency and accuracy comparable to 6-coordinate and higher-coordinate diameter measurement schemes.
The standard form of the scheme does not have high accuracy rates, however, by changing the location of the probing beams. The size of the so-called "dead" zones can be minimized (figure 4).

The following is a comparative table of the size of the "dead" zones and the ratio with the diameter of the controlled object (table 1) is presented below.

**Table 1.** Comparison of the size of dead zones and the ratio with the diameter of the controlled object.

| Method                     | Dead zone scheme | The ratio of the maximum/minimum possible missed defect (in% of the diameter of the controlled object) |
|----------------------------|------------------|--------------------------------------------------------------------------------------------------|
| 1. According to 2 coordinates | ![Diagram of 4-axis meter] | 19...22.5%                                                                                       |
| 2. According to 3 coordinates | ![Diagram of 4-axis meter] | 4.1...22.5%                                                                                      |
| 3. According to 4 coordinates | ![Diagram of 4-axis meter] | 4.1...5.1%                                                                                       |
| 4. According to 6 coordinates | ![Diagram of 4-axis meter] | 1.2...1.8%                                                                                       |
5. According to 4 coordinates (2 photosensitive elements) 1…10.8%

6. According to 4 coordinates, with displacement (2 photosensitive elements) 3.5…5.2%

According to the histogram of the ratio of "dead" zones with the diameter of the controlled object, it is possible to conclude that the presented prototype of the diameter meter construction on the basis of the 4-coordinate method with an offset, helps to obtain an accuracy comparable to the 6-coordinate method. The use of only two sensitive elements provides a lower cost of production of both a peculiar device and the system as a whole.

Figure 5. Correlation of dead zones with the diameter of the controlled object.

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