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Enlargement of measuring zone in laser gauges without sacrificing measurement accuracy

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ABSTRACT

The paper proposes methods of enlarging the measuring zone in laser diameter gauges without sacrificing the measurement accuracy. Possessing a large measuring zone, such gauges are designed to measure external diameters of round wire materials whose diameter exceeds the laser diode wavelength (~0.5 mm and longer). A method of the video quality improvement is proposed herein, and algorithms are developed to detect the optimal geometrical parameters and estimate observational errors within the measuring zone of the laser diameter gauge.

1. Introduction

In existing research and industrial applications, different methods are widely used in measuring the outer diameter of products of various function and purpose. In particular, mechanical [1], magnetic [2], and ultrasonic techniques [3,4] are very common in diameter measurements. An optoelectronic technique for diameter characterization which is based on the diffraction theory in combination with image processing techniques is often used in engineering and production technology. For example, laser diameter gauges are widely used in the cable industry, which provide the distribution of both divergent and parallel beams of light [5–7]. The diameter measurement must ensure the required quality of cable products as well as the material saving and power consumption. The cable production process is complicated (Fig. 1) and requires monitoring a multitude of parameters such as eccentricity [8], unit-length capacitance [9,10], and also insulation strength testing [11,12]. The diameter gauging is performed at high speeds achieving 3000 m/min, and also at strong cable vibrations which have an adverse effect on the quality of measurements. In order to meet constantly growing demands to the measurement accuracy of cable diameters, manufacturers are forced to look for alternative techniques for reducing measuring errors.

In present-day productions, laser optoelectronic diameter gauges with a 15–60 mm measuring zone are widely used for the characterization of diameters of round wire materials [13–16]. For objective reasons, all measuring devices possess errors. During the lot production of laser diameter gauges, their adjustment and calibration take a good deal of time, but are necessitated partly by the difficulty in maintaining their all design sizes. Therefore, a manual calibration of each diameter gauge becomes impossible. For operational instruments of interest, it is very important to ensure the subscribed error throughout the entire measuring zone and not only in the vicinity of its centre, as is the case with most manufacturers. In the cable production, it's not possible to use the efficient centering methods, in particular, at a stage of wire extrusion or varnishing, when the coating is not yet polymerized. Additionally, a steady-state vibration of the product does not allow it to locate in the centre of the measuring zone. In this work we propose a range of design and algorithmic decisions allowing to create the instrument the error of which does not change when the position of the monitored object changes. We also propose a method to simplify and automate the adjustment of laser gauges in the lot production. We offer the procedures to minimize observational errors when measuring diameters with reference wire gauges. These procedures include the quality improvement of the optoelectronic diameter gauges, determination of their geometrical parameters, and automated calibration using reference gauges.

2. Material and methods

2.1. Video quality improvement

Let us consider the optical method to get the diameter value. The laser diameter gauge receives cell numbers as input parame-

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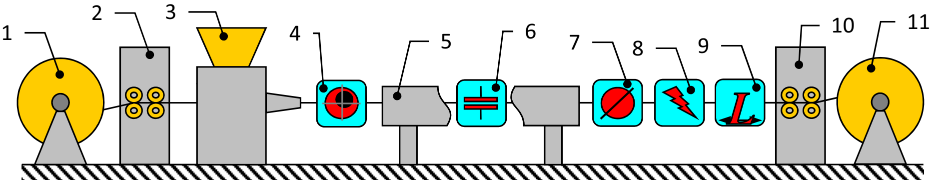

Fig. 1. Flow chart of cable production process: 1 – pay-off drum; 2 – pull-off device; 3 – extruder; 4 – eccentricity gauge; 5 – quenching bath; 6 – capacitometer; 7 – diameter gauge; 8 – high voltage tester; 9 – length and velocity measuring system; 10 – wire forming device; 11 – take-up drum.

ters which correspond to the shadow boundaries on both modules of the charge-coupled device (CCD). The detection of cells matching the shadow boundaries was presented in [17]. This geometrical model includes the point radiation sources which usually represent a semiconductor laser or a laser diode with 808 nm wavelength, the beam divergence at angles in the range of 35–42 degrees, and the power consumption ranging between 200 and 500 mW. A detailed description of the similar measuring systems was given in our previous works [18,19].

Using laser diodes without accessory optics as presented in Fig. 2 provides a range of advantages such as simplicity in design, compactness of the radiation source and its low cost. However, there are certain limitations related to the non-uniform distribution of the luminous flux within the measuring zone and its heavy losses without optimization of the laser beam. More powerful radiation sources should be used owing to the low laser beam efficiency which also increases the exposure time and causes stray light in the optical system which modifies the total observational error. Non-uniform stray lighting can lead to the additional inadmissible error. When measuring the eccentricity of a workpiece, the observational error of its position within the measuring zone should not exceed several microns. Therefore, the uniform distribution of the luminous flux should be provided within the measuring zone. As can be seen from Fig. 2, the laser diode generates a cone-shaped beam, the base of which is an ellipse having long and short axes $\theta\perp$ and $\theta//$, respectively. In this optical transducer, the orientation of laser diode allows the linear CCD to arrange along $\theta\perp$ axis and normal to $\theta//$ axis.

The luminous flux generated in $\theta\perp$ plane by an ordinary laser diode, as shown in Fig. 3, is described by the normal (or Gaussian) distribution. So, the laser intensity in the CCD centre is always higher than at its periphery. The difference between laser intensities is not problematic because the angle α limited by the length of the linear CCD module does not exceed 15–20 degrees. Local random changes in the laser intensity contribute much more to observational errors. These changes are caused by the random distribution of the luminous flux along $\theta//$ axis. Even a small difference between the relative orientation of the laser diode and CCD module leads to a non-uniform distribution of the luminous flux. Each laser diode possesses its individual properties which can cause the non-uniform distribution of the luminous flux. Additionally, the optic's surface is inevitably contaminated with dust particles or the like during the operation, thereby intensifying non-uniformity. Sometimes, it entails such troubles as the increase in observational errors and equipment failures.

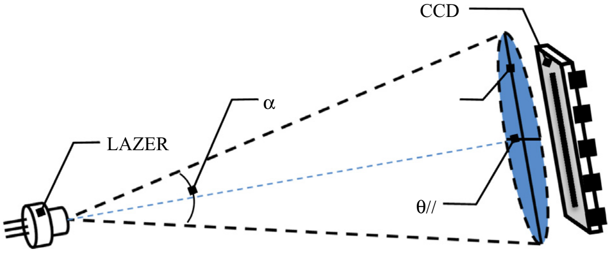

Fig. 2. Schematic orientation of laser diode without accessory optics relative to CCD module.

One of the ways to eliminate the non-uniform distribution of the luminous flux produced by the laser diode is to use the accessory optics comprising a collimator with the Powell lens. The schematic orientation of the laser diode with accessory optics is shown in Fig. 4. This method is widely used in science and technology [20–23]. The collimator is intended to obtain collimated or parallel laser beams with the diameter of 1.5–2 mm. The collimated beam transforms to the divergent beam again when passing through the Powell lens. The angle α of the beam divergence is the same, and the laser intensity distribution is uniform, without local changes. The width of the laser beam passing through the Powell lens is 1.5–2 mm. Thus, almost the whole luminous flux hits the linear CCD that allows us to apply a lower laser power and reduce the exposition time, thereby enhancing the dynamic properties of the optical system.

2.2. Optimization algorithm for geometrical parameters

The diameter of round wire materials is measured according to the proposed geometrical model presented in Fig. 5.

The optimization algorithm can be described by mathematical calculations to find the workpiece diameter. The obtained values of the shadow boundaries are transformed to physical values. Using the initial geometrical parameters, the workpiece diameter can be obtained. Let us introduce the following notation for the initial geometrical parameters:

C_x, C_y are distances respectively from the zero point to N_X and N_Y cells, where the laser beam is normal to the CCD module;
N_x, N_y are cell numbers at the points of intersection with optical axes;
H_x, H_y are distances between the CCD modules and point radiation sources.

The coordinate axes coincide with the CCD modules. At first, the cell numbers obtained for the shadow boundaries are converted into length units using the following formulas:

$$X_{11} = (N_{x1} - N_x)\mathrm{res} + C_x;$$

$$X_{21} = (N_{x2} - N_x)\mathrm{res} + C_x;$$

$$Y_{11} = (N_{y1} - N_y)\mathrm{res} + C_y;$$

$$Y_{21} = (N_{y2} - N_y)\mathrm{res} + C_y,$$

where *res* is the resolution of the CCD module, μm per cell.

Secondly, let us calculate the projection of the workpiece centre X_{01} and detect the angles of α_{x1} and β_{x1}. Next, the following equations are obtained for X_{01} and Y_{01}: