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Non-Contact Measurement System Analysis for Metallurgical Slabs Proportion Parameters

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***Abstract*—The article describes design and development of a measuring system that allows to measure the selected size and shape variations of a steel slabs with a defined precision. The developed measurement system allows obtaining accurate information on the dimensions of the material that enters the rolling mill. More precise information about dimensions of the material entering the rolling mill ultimately brings significant savings of the metal material. The proposed methodology of testing of different types of non-contact measurement for steel materials is used for the design and management of industrial applications with specific requirements.**

***Index Terms*—Optical sensor, measurement system, accuracy, metallurgy, slab.**

I. Introduction

Contactless measurement techniques are used for measuring dimensions, distances and surfaces of hot or cold materials, in industrial environments of production halls (Fig. 4). These environments are characterized by aggressive conditions — dust, heat, vibration, chemical fumes, interference from the power line, etc. [1].

Contactless measurement of distance, size and position of materials in industrial applications is performed with capacitive sensors, linear inductive sensors, magneto - inductive sensors, confocal sensors, laser distance sensors, and eddy current sensors [2]. For accurate measurement of velocity and length of moving surfaces an industrial laser Doppler velocity meter has been developed [3]. For accurate measurements at greater distances photoelectric sensors or laser sensors, which operate on the triangulation principle, are suitable [4]. For metallurgical industry, with regard to the specific shapes, surfaces and environment, photoelectric sensors and laser sensors that represent the most appropriate and most accurate solution for this type of applications were chosen for the measurement implementation.

Triangulation is a method for distance measurements, often using a laser. The high detection speed makes it possible to monitor the position of a moving or vibrating part e.g. of some machinery. For diffuse reflections, the distance can be limited by the requirement to receive a sufficient amount of reflected optical power; with specular reflections, much larger distances, can be measured, but some kind of angular alignment is required [5].

Photoelectric sensors operate on the principle of measuring the time of flight of light and are designed for non-contact distance measurement. The principle of operation consists in sending a laser pulse and measurement of the time before the pulse reflects back to the receiving optics sensor. Based on the measured speed of light and the time it is possible to calculate the distance. According to the measurement task and required measuring range sensors work against diffusely reflective surfaces or against special reflective boards [6].

Methodology for measurement of both types of sensors is realized using a specially developed two modules. One module contains measuring body-surface steel, which are placed at precise distances with maximal deviation ±0.5 mm. These deviations in structure do not bring up any error precision for sensors measurement, because both types of sensors are tested on the same measurement module. The second module is composed of movable part on which the sensor is located. It enables smooth movement of the sensor to the sides to verify the distance of the measuring points and it also enables to verify the accuracy in sensor repeat ability together with the different speed of movement of the sensor during measurement process. The sensors were verified in possible maximal angle for correct measuring of reading measured body-surface steel.

II. Requirements for Measuring System and Conditions of Measurement

To measure dimensions and shapes of slabs our workplace designed and developed a measuring system with a defined precision measurement of selected dimensions of the material entering the rolling mill. More precise information about dimensions of the material entering the rolling mill ultimately brings significant savings of the metal material.

The measurement results are transferred from the measuring system to the superior information system in the form of average values of the measured quantities, to achieve more precise results. The required accuracy of the average values of slab dimensions obtained from the

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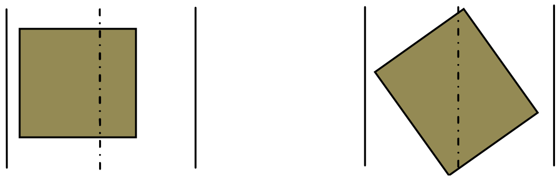
measured values is specified: accuracy of thickness measurement is $H \pm 1.0$ mm, accuracy of width measurement of the material is $B \pm 2.0$ mm.

The influence of different temperatures on the dimensions of the slab can be eliminated by algorithms based on a calculation using the measured temperatures of slabs. The measured slab can be situated in a position perpendicular to the measurement system axis or in a slightly displaced position (Fig. 1).



a) b)

Fig. 1. The measurement positions of slabs on flatbed, a) parallel with the edge of the slab, b) slabs rotated by 45°.

The maximum assumed moving speed of the material is v = 0.4 m/s. The opto-sensor NCDT 1700 and laser opto-sensor NCDT ILR 1182 from Micro-Epsilon Company are selected based on described specific technical characterization [7].

III. Measuring System Verification with Opto-Sensor NCDT 1700 Micro-Epsilon

A. *The Opto-sensor NCDT 1700 Description*

The opto-sensor NCDT1700 is intelligent laser optical displacement measurement device. NCDT1700 consists of laser-optical sensor and a signal conditioning electronics. The sensor uses the principle of optical triangulation. Modulated point of light is projected onto the target surface. This sensor is operating with a semiconductor laser with a wavelength of 670 nm. The laser is operated on a pulsed mode, the pulse frequency corresponding to the measuring frequency. Measuring range is 500 mm, start of measuring range is 200 mm, midrange is 450 mm, end of measuring range is 700 mm, linearity is ± 0.08 %, accuracy of sensor is 30 μm from technical documentation [7].

B. *Design and Implementation of Testing with Opto-sensor NCDT 1700*

The specific application for the original measuring and data storing has been created on the basis of standard knowledge of the communication. The purpose was to verify correctness of the communication and the measured data and the ability to detect measurable distance and distance outside the measurable area.

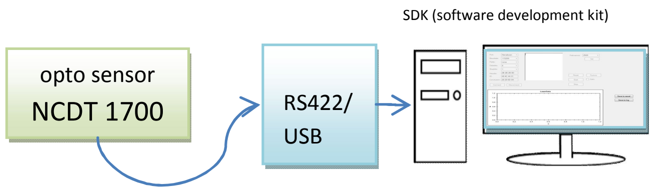


Fig. 2. The measuring system with laser opto-sensor NCDT 1700.

The laser sensor link with a PC is realized by RS 422 bus using converter RS422/USB (Fig. 2) with SDK (software development kit) system library.

The original specific measurement application was created in a C # program. The measurement was performed on the developed movable module. The module was designed with the mounted laser sensor, which measured the distance to the sample slabs (Fig. 3).

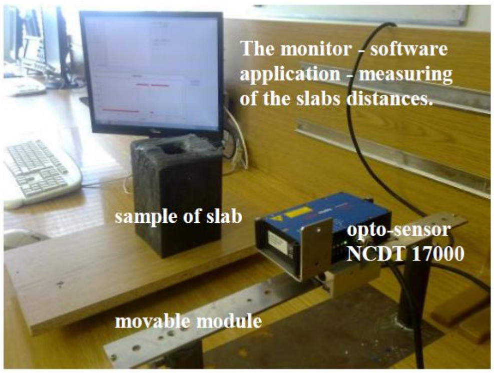


Fig. 3. Non-contact measurement system with opto-sensor NCDT 1700 and movable module.

C. *Measurement parameter setup*

The slab measurement focused on several types of significant rotation: a) parallel with the edge of the slab (Fig. 5), b) slabs rotated by 45° (Fig. 6), c) a piece of slab with ground arc, d) vertical shift (Fig. 7). During measurement the movable module was moved at distances of 200 mm, 390 mm and 485 mm (Fig. 3).

Fig. 4. Industrial environment for the installation of measurement system for non-contact dimension of measurement slabs.

D. *Evaluation of the measurement with opto sensor NCDT 1700*

Measurement with NCDT 1700 was performed at the specified speeds (Table I), even at speeds above 0.5 m/s.

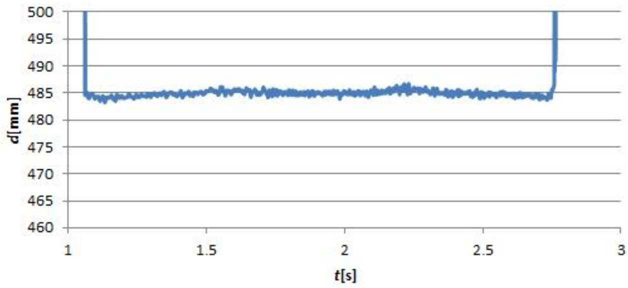


Fig. 5. The dimension measurement of the slabs at the distance d = 485 mm, speed v = 0.068 m/s (Table I).

Measurement against direct solar light leads to erroneous distance detection. Data transfer using data communication bus RS422/USB does not allow for direct synchronization but the data are gradually sent in data packets. With increasing distance from the measured object the average relative error decreased (Table I).

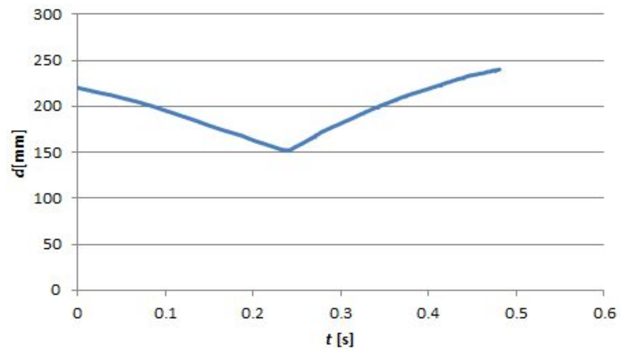


Fig. 6. The dimension measurement of the slabs, which is rotated by 45°, at the distance d = 200 mm, speed v = 0.332 m/s.

The most accurate measurement was taken at the distance d = 485 mm (Table I). Error rate of measurement is visible on the edges of the slab too obliquely oriented with respect to the scanned beam (Fig. 7).

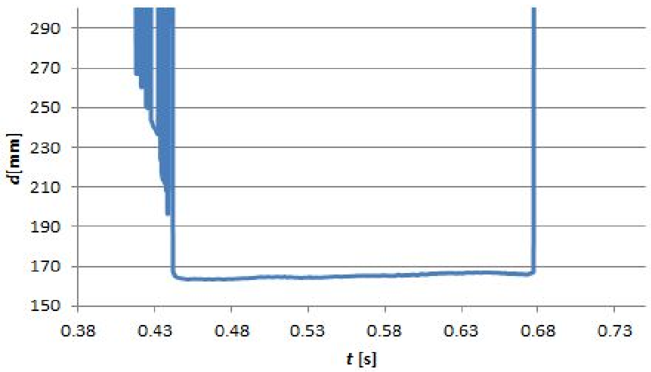


Fig. 7. The time courses of dimensions measuring of the slabs for vertical rapid movement displacements v = 0.464 m/s.

TABLE I. EVALUATION OF THE MEASUREMENT WITH OPTO-SENSOR NCDT 1700.

Distance of the sensor from the slab *D* [mm]	Speed of shift *v* [m/s]	Calcu-lated width of the slabs *b* [mm]	Average measured distance sensor from slabs *d* [mm]	Mean square error arithmetic average [mm]	Average relative error [%]
200	0.08	115	195.79	$8.75.10^{-3}$	2.13
390	0.09	114.97	392.93	$7.80.10^{-3}$	0.72
485	0.07	115.11	485.03	$9.31\ .10^{-3}$	0.02

IV. VERIFICATION OF MEASURING SYSTEM WITH OPTO-SENSOR NCDT ILR1182 MICRO-EPSILON

A. Description of Opto-sensor NCDT ILR 1182

Sensor in the opto-sensor NCDT ILR 1182 is optoelectronic sensor for noncontact distance and displacement measurement for industrial applications. The opto NCDT ILR 1182 is a laser range finder to measure distances from 0.1 m up to 150 m with pinpoint accuracy. A given target can be clearly identified with the help of a red laser sighting point. The range finder works based on comparative phase measurement. It emits modulated high-frequency light which is diffusely reflected back from the target with a certain shift in phase to be compared with a reference signal. From the amount of phase shift, a required distance can then be determined with millimeter accuracy. Linearity is ±2 mm (+15 to +30°C), ±5 mm (−10 to +50 °C), resolution is 0.1 mm from technical documentation [8].

B. Design and Implementation of Testing with Opto-sensor NCDT ILR 1182

Measurement of the sensor ILR 1182 quality and accuracy was focused on: a) testing of the influence of light on accuracy of measurement, b) testing of the influence of tilt on quality of measurement, c) testing of the effect of the nature of the surface material on quality of measurement, d) testing of measurement accuracy for different distances: 1 m, 3 m, 7 m, 10 m, e) testing of accuracy of dimension measurements of slabs in slow and fast motion, f) testing of accuracy of repeated tests.

The results of testing and their accuracy are to a certain extent influenced by the conditions of the slab attachment and of the very test execution of testing in laboratory areas that are not ideal for this kind of testing. The actual test results, however, still provide sufficient informative value, which allow for the conclusions whether the sensors are applicable for the given measurements or not.

The measurement sensor accuracy testing was performed on a specially created measurement module that had 2 special surfaces in standard distances 400 mm and 1000 mm and 2 surfaces in distance 0 mm on the left and right sides. This measurement module, respectively surfaces points in distance 0 m, were measured in various distances from movable module, respectively from sensor NCDT 1700 - 200, 390, 480 mm and from sensor ILR1182- 1000, 3000, 7000, 10000 mm [9].

Each of the surfaces was initially ground, but still turned out to be hard to detect by the sensor. Error messages appeared. That is why the surfaces were covered up with self-adhesive paper.

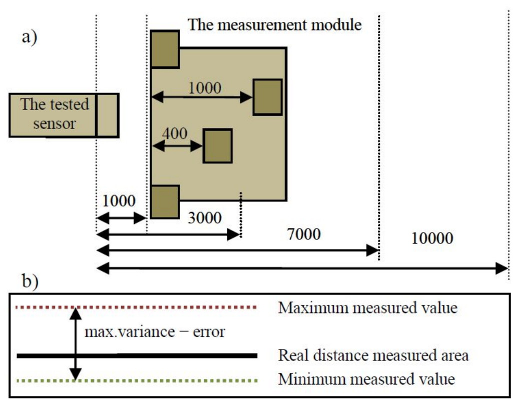


Fig. 8. Design of measuring system with opto-sensor NCDR 1700 a) measuring system for determination of deviation, b) description of deviation measurement (max. variance = max. value − min. value).

C. Measurement evaluation with opto -sensor NCDT ILR1182

The accuracy of the measured values is not affected by night measurements, standard room lighting or a strong light source.

It was found that a sufficient precision measurement angle is up to approximately 20°, when exceeded incorrect measurements and error reporting may result.

Different surface variants tested ranged from rough to smooth and from dull to shiny. Relatively good measurement properties were detected for most types of surfaces. Measurements on glossy smooth surfaces were affected by errors from excessive lighting and from excessively large reflection values. Measurements of the other material surfaces were performed without occurrence of error messages.

TABLE II. MEASURED VALUES – MEASUREMENTS ACCURACY TESTING IN DIFFERENT DISTANCES WITH SENSOR ILR 1182.

Distance from sample [mm]	**Measurement surface on slabs sample [mm]**				**Deviations [mm]**	
	0 mm left side	**0 mm right side**	**400 mm center**	**1000 mm back**	**Devia-tion on 400 mm**	**Devia-tion on 1000 mm**
1000.2	0.5	0.7	401.0	999.1	0.45	**−1.5**
3000.8	−0.1	−0.3	400.1	998.5	0.30	−1.3
6993.1	0.6	0.1	400.7	1000.5	0.31	0.1
9999.48	0.85	0.72	401.1	1001.3	0.27	0.5

Accuracy of measurement and testing in different distances of 1 m, 3 m, 7 m and 10 m were adversely affected by the method of mounting the sensor in the given distance from the measured sample. The measurement values were still influenced by deviations from the measured value by about ± 0.2 mm, even though filtration was used and 5 measured values were averaged.

Measurement of the measured surfaces in movement in the distances: right 0 mm, 1000 mm, 400 mm, left 0 mm (Fig. 8), (Table III). Between surfaces 1000 mm and 0 mm left is a space with a large distance of the back wall, where the values were adjusted by −100 mm. Maximum deviations of measured values are shown in Table III.

TABLE III. MEASURED VALUES - MEASUREMENTS ACCURACY TESTING IN MOVEMENT WITH SENSOR ILR 1182.

Distance of sample [mm]	**Deviations [mm]**			
	0 mm right	400 mm	1000 mm	0 mm left
1000	0.14	**0.74**	0.44	0.36
3000	0.26	0.43	0.46	0.33
7000	0.36	0.71	0.29	0.31
10000	0.30	0.41	0.764	0.29

TABLE IV. MEASURED VALUES – MEASUREMENTS ACCURACY TESTING OF REPEATABILITY MEASUREMENTS WITH ILR1182.

Distance from the sensor [mm]	**Deviations [mm]**	
	0 mm	1000 mm
3000	0.47	**1.87**
7000	1.00	0.76
10000	0.68	1.21

Furthermore the movement was repeated at the same point of the measured surfaces at a defined distance (Table IV). The movement was always stopped outside the defined distance with return back to the initial position. To determine the maximum deviations extreme values of transition of the measured surfaces were excluded (Table IV).

The measured results show that the maximum deviation of the slow movement is 0.737 mm (Table III). For repeatability of measurement the maximum deviation is 1.87 mm (Table IV). The maximum deviation in the static measurement with averaging of 5 values was 1.45 mm (Table II). The high value of the deviation is caused by the recorded amplitude values.

V. CONCLUSIONS

The purpose of the paper was to verify design and structure of a measurement system for the most suitable sensor type for non-contact dimension and distance measurements of moving slabs under industrial conditions. Results and comparisons of the dimension measurement accuracy of slabs were evaluated. The tested opto-sensor NCDT 1700 is more robust in high speed movement measurements v = 0.5m/s. The tested opto-sensor ILR 1182 depends on the sampling measurement frequency. On the other hand, opto-sensor ILR 1182 allows for measurements across longer distance up to 150 m compare to 70 cm and is suitable for larger materials than the compared opto-sensor NCDT 1700. Moreover sensor ILR 1182 is more resistant to influences of light sources. Each measurement was repeated 20 times. The number of measurements precisely determines the accuracy and repeatability of the sensors. Both the tested sensor types are suitable for the industrial slab distance measurement system where the choice of the sensor type depends on the specification requirements.

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