733. Laser beam optical focusing method for measurement of angular sensor glass scale quality parameters

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Abstract. This paper introduces alternative to existing, glass scale quality parameters measurement method based on optical focusing, which is used in optical disk data reading. Using relatively simple data processing algorithms we were able to detect possible errors and position of the errors on the glass scale. Research showed that measurement method could be used for quality parameters evaluation, but requires usage of the laser pick up heads with known parameters.

Keywords: glass scale, optical focusing, encoder, glass scale defects, quality control, angular encoder.

1. Introduction

Angular encoder parameters are determined by the quality of the used glass scale. Possible errors of the glass scale are mechanical damage, contrast at the edges of the elements of the scale and basis thickness variation (dispersion). Usually quality control of the scale is done with camera and microscope. The equipment is complex, expensive and cannot measure basis thickness. Other possible quality control methods are based on laser interferometry [1]. Method has a lot off advantages but is rather expensive.

In this article we analyze less expensive quality control method based on optical laser beam focusing and mechanical cross-ply gear. Cross-play gear is used for the measurement zone selection (metalized surface, zero mark or position marks). The method can be used for surface roughness or unevenness evaluation as well.

Experimental measurements showed that method ensures stable results and can be used for glass scale quality evaluation. In this paper we present possible glass scale defects, both the theoretical and measured, possible defect detection methods and working principle of the measurement system.

2. Quality parameter modelining and evaluation methods

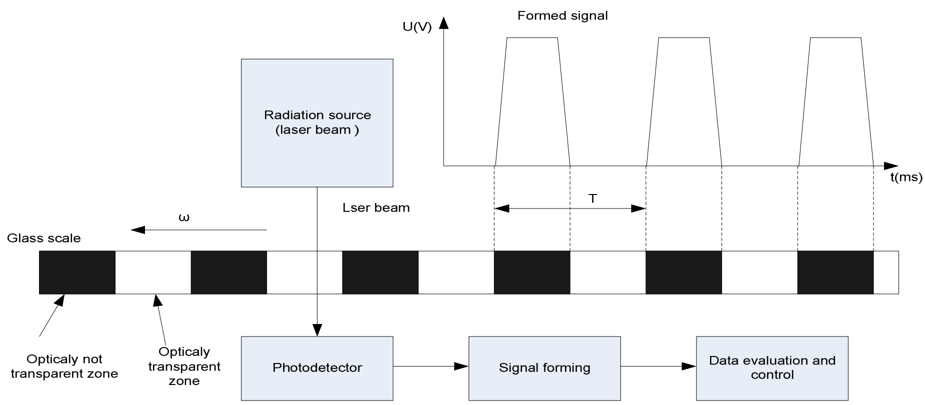

Fig. 1. Typical mark reading system (encoder)

Signals of the typical encoder are obtain according to Fig 1. Reference optical system is interconnected with measured mechanical system. Movements of the mechanical system form electrical signals. Number of the signal impulses or code change is proportional to the displacement of the mechanical system.

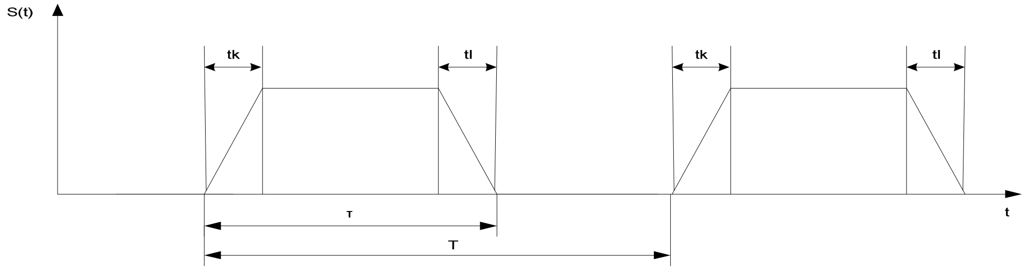

Fig. 2. Measurement signal

In this signal it's possible to define parameters:
Signal duty cycle:

$$n = \frac{\tau}{T} \quad (1)$$

T – signal period, τ – duration of impulse , n – duty cycle.
Impulse rising edge coeficient:

$$K_{kil} = \frac{t_{kil}}{T} \qquad K_{kil}[0......1] \quad (2)$$

K_{kil} – impulse rising edge koeficient, T – impulse periode, T_{kil} – impulse rising edge duration.
Impulse falling edge coeficient:

$$K_{kr} = \frac{t_{kr}}{T} \qquad K_{kr}[0......1] \quad (3)$$

K_{kr} – impulse falling edge coeficient, T_{kr} – impulse falling edge duration.
Avarege signal voltage:

$$\overline{U}_i = \frac{1}{n}\int_{t_2}^{t_1} U_i dt \quad (4)$$

t_1, t_2 – evaluation time, U_i – measured sample voltage, $\overline{U_i}$ – average voltage of the period, n – number of measurements per period.

Possible signal with Z axis defects is shown in Fig 3.

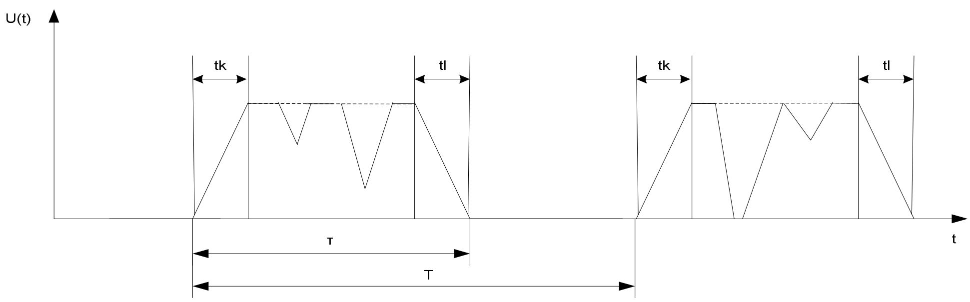

Fig. 3. Measurement signal with Z axis glass scale defects

Signal time comparison method is shown in Fig. 4.

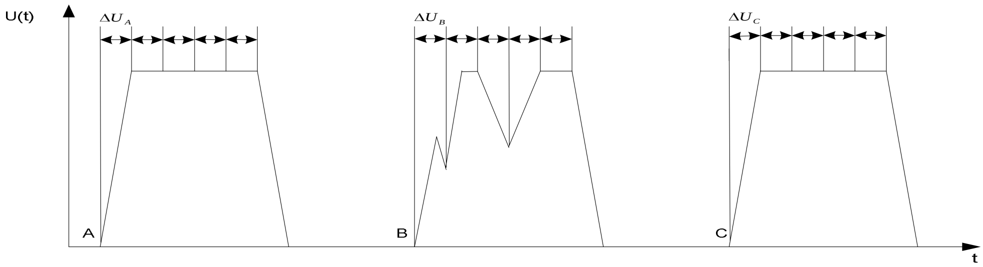

Fig. 4. Signal time comparison method visualisation

Signal time comparison method is based on signal sample comparison. These parameters are amplitude of the sample voltage and increase or decrease of the amplitude. Evaluation is done by counting number of differences of the different period voltage samples. Decision about defect is based on number of the differences per signal period. In this case the threshold was selected manually, but it is possible to use adaptive threshold level search algorithm based on number of samples per period. Method is described by following equation system:

$$\begin{cases} if, U_i > U_{i+1}, U_{i+nul_i} > U_{i+1+nul_i}, U_{i+nul_{i+1}} > U_{i+1+nul_{i+1}} \\ , i = i+1; \\ if, U_i < U_{i+1}, U_{i+nul_i} < U_{i+1+nul_i}, U_{i+nul_{i+1}} < U_{i+1+nul_{i+1}} \\ , i = i+1; \\ if, U_i < U_{i+1}, U_{i+nul_i} > U_{i+1+nul_i}, U_{i+nul_{i+1}} > U_{i+1+nul_{i+1}}, \\ Defnr_i = i, i = i+1; \\ if, U_i > U_{i+1}, U_{i+nul_i} < U_{i+1+nul_i}, U_{i+nul_{i+1}} > U_{i+1+nul_{i+1}}, \\ Defnr_i = i + nul_i, i = i+1; \\ if, U_i < U_{i+1}, U_{inul_i} > U_{i+1+nul_i}, U_{i+vid_{i+1}} < U_{i+1+nul_{i+1}}, \\ Defnr_i = i + nul_{i+1}, i = i+1; \\ if, U_i > U_{i+1}, U_{i+nul_i} < U_{i+1+nul_i}, U_{i+nul_{i+1}} < U_{i+1+nul_{i+1}}, \\ Defnr_i = i, i = i+1; \\ if, U_i < U_{i+1}, U_{i+nul_i} > U_{i+1+nul_i}, U_{i+nul_{i+1}} < U_{i+1+nul_{i+1}}, \\ Defnr_i = i + nul_i, i = i+1; \\ if, U_i > U_{i+1}, U_{i+nul_i} < U_{i+1+nul_i}, U_{i+nul_{i+1}} < U_{i+1+nul_{i+1}}, \\ Defnr_i = i + nul_{i+1}, i = i+1; \end{cases} \tag{5}$$

where U_i – i-sample voltage; *Defnr* – number of defect; *nul* – zero cross index.

Evaluation of signal modulation is based on Fig. 5.

The modulation can be defined as a function:

$$\Delta U = f(\Delta d, \Delta\alpha), \tag{6}$$

where Δd – measurement surface error (glass thickness error), $\Delta\alpha$ – rotation angle error, ΔU – modulation amplitude.

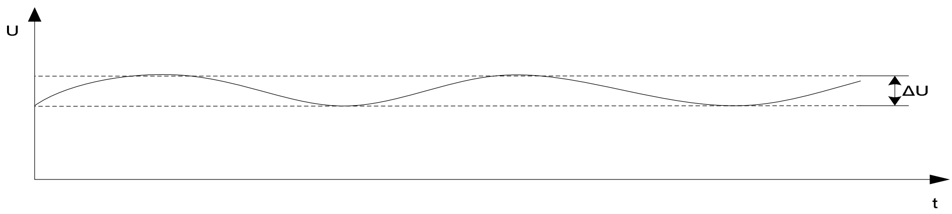

Fig. 5. Modulated signal voltage

Influence of each error element can be evaluated according to spectrum of the modulated signal. Each error element will make additional harmonic in signal spectrum. Evaluation can be done according to the equation 7:

$$DFT(\Delta U) = f(U_d, U_\alpha, ...) \quad (7)$$

where $DFT(\Delta U)$ – discrete Fourier transformation of modulation amplitude, U_d, U_α – feasible error elements.

3. Optical focusing method analisys

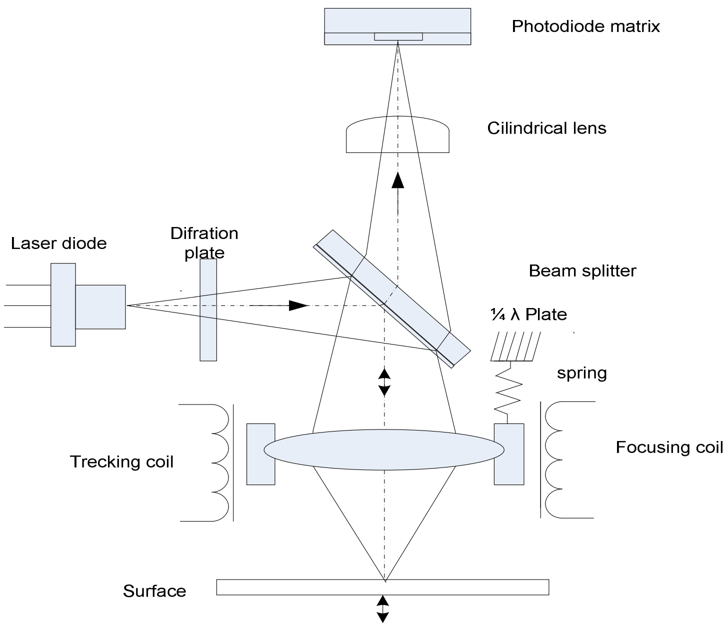

Fig. 6. Optical focusing system structure

By the means of the diffraction plate laser beam is split into 3 beams. Central beam intensity is highest 50%. Side beams intensities 25%. A beam passes ¼ λ plate. The plate is made from crystal anisotropic material. Materials beam bending angle is dependent from laser beam polarization plate. After beams pass ¼ λ plate the polarization of the beam is rotated by 45^o

angle and reflected from beam splitter. The prism focuses beams on the surface of the measured material. After that this beam is reflected back with 180^o polarization angle shift. Because polarization angle is changed, beam splitter passes reflected beam to the cylindrical prism and photodiode matrix. The matrix consists of the 6 sectors. 4 Sectors are used for tracking central beam, 2 sectors for tracking side beams. Reflected beams aperture depends from the reflection point. So the purpose of the cylindrical lens is to change beams aperture that passes to the detector (without cylindrical lens, form of the aperture would be always circular). Possible beam apertures and measuring signals are shown in Fig 7.

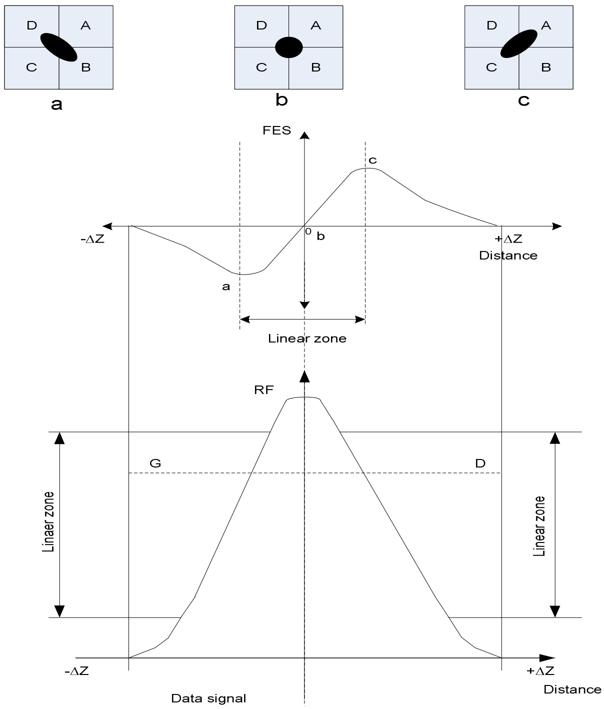

Fig. 7. Possible photodiode matrix aperture and measurement signals

Beam aperture depends from the focusing point. Focused beam has circular aperture shown in (Fig 7. b). When beam is out of focus aperture can change to Fig 7a or Fig 7c. Hence beam aperture change forms different detection signals that are proportional to the distance from the focusing point. There three types of signals that can be used for data evaluation. Focus error signal (*FES*) data signal (*RF*) and tracking signals from E and F sectors. Signals are formed according to 8 and 9 equations.

$$FES = (S_A + S_C) - (S_B + S_D) \quad (8)$$

FES – focus error signal; S_A, S_B, S_C, S_D – photodiode matrix zone signals.

RF signal is obtained according to equation 9:

$$RF = S_A + S_B + S_C + S_D \quad (9)$$

where *RF* (Radio Frequency) – data signal.

4. Optical focusing system static calibration

Static characteristic of the measurement system were obtained using measurement scheme shown in Fig 9. These characteristic enable evaluation of the linear measurement range and measurement sensitivity.

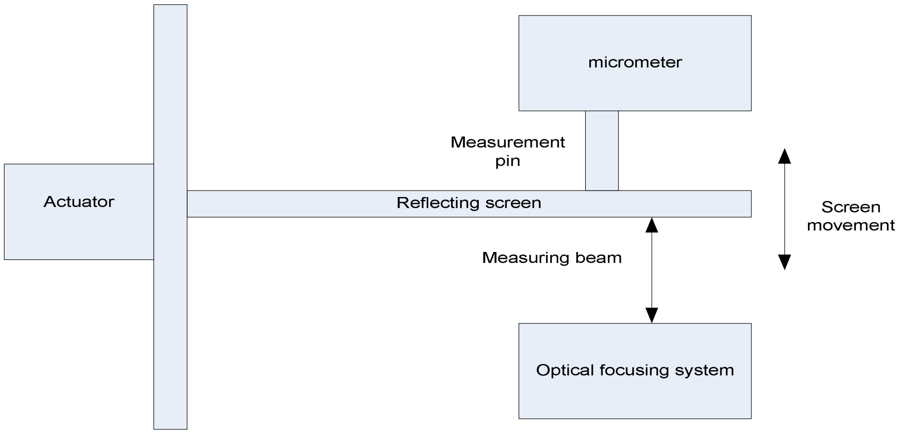

Fig. 8. Static measurement system calibration structure scheme

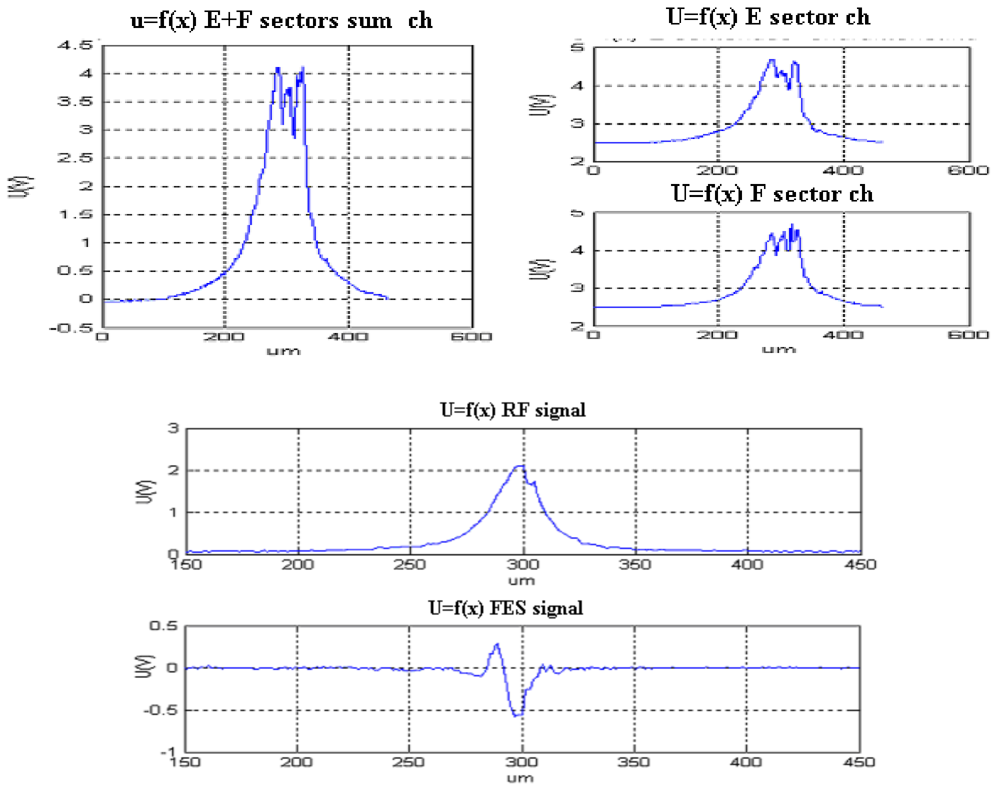

Fig. 9. Static measurement system calibration results

5. Glass scale dinamic measurement and error detection

Dynamic measurement and glass scale defect evaluation was done according to Fig. 10 structure scheme.

Measurement results are shown in Fig. 11. Time comparison defects evaluation method was used for possible defects evaluation. Some of the found defects are enlarged and shown in Fig. 11.1, Fig. 11.2, Fig. 11.3 and Fig. 11.4.

We have excluded signal modulation amplitude in Fig. 12. Modulation can be the result of non-ideal rotation angle or surface thickness variation. For more accure evaluation further analysis is needed.

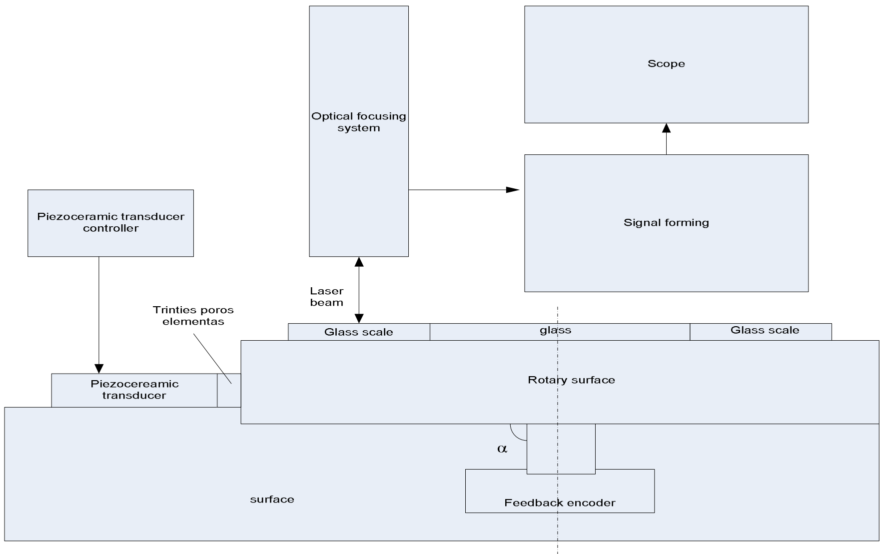

Fig. 10. Glass scale measurement structure scheme

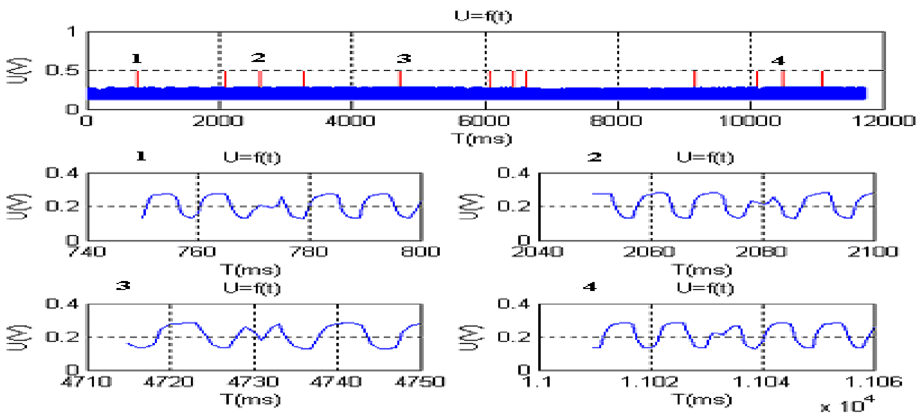

Fig. 11. Measured glass scale surface signal and detected errors

Conclusions

Experimental and theoretical characteristics are similar. Hence analyzed theoretically measurement signals (*FES* and *RF*) can be used for measurement.

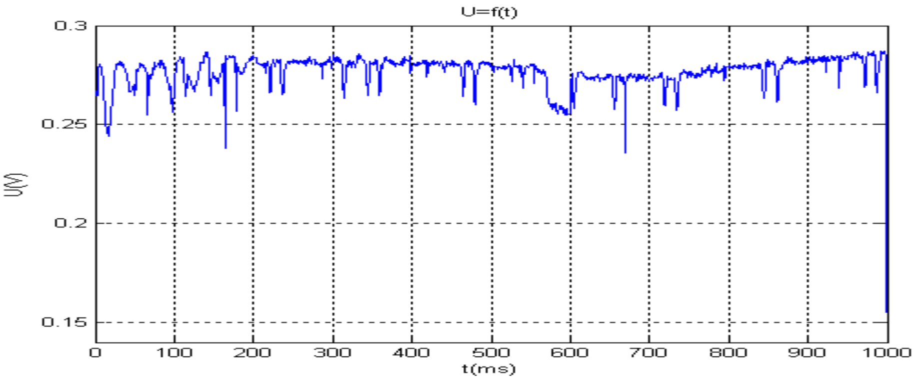

Fig. 12. Signal modulation amplitude

Measurement can be done in linear zone of the characteristics. According to the static characteristics when bigger measurement dynamic diapason is needed measurements should be done by using *RF* signal. Focus Error signal should be used when there is a need to measure very small displacements and have minimum beam aperture. Other possible measurement method is to use E or F sector signals. In this case we get bigger beam aperture and less sensitivity but higher signal voltage.

Dynamic glass scale measurement and evaluation showed that measurement system can be used for error detection and quality parameters evaluation. Error detection was done using signal time comparison method so the suggested algorithm is usable for error detection.

Experimental data showed that there is a need for precision positioning of the glass scale. One of the possible positioning method's could be the usage of piezoelectric bimorphs [8].

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