Probabilistic and Statistical Characteristics of Signals in Mirror through Transmission Technique on Multiple Reflections for Rod Cross Section Ellipticity Testing

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Abstract. This article suggests an approach to validation of new informative parameters in mirror through transmission electromagnetic-acoustic technique on multiple reflections for cylindrical object ellipticity testing, based on probabilistic and statistical analysis of multiple reflection series. The results of data array analysis obtained in the process of multiple reflection oscillogram modeling are presented. Behavior of probability density distribution, dispersion, root-mean-square deviation and asymmetry, depending on ellipticity value, is shown. Their applicability as informative parameters is introduced.

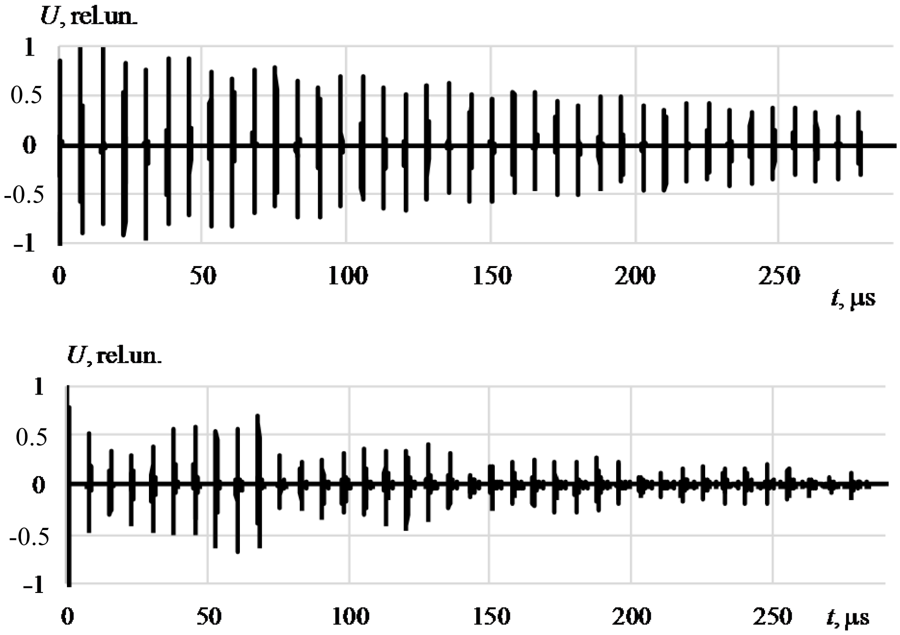
Keywords: ellipticity, rod, multiple mirror through transmission technique, probabilistic and statistical analysis

INTRODUCTION

The need for cross section shape testing arises in the process of circular section rod production. Defects of cross section shape deviation from roundness called cross section ovality (ellipticity) appear due to equipment deterioration or other factors. During rod manufacturing cross section ellipticity is detected by general-purpose measuring tools such as a caliper rule, a micrometer, a roundness measuring tool. One of promising problem-solving methods in non-destructive testing, material property characterization and thickness gauging of bar steel rolled stock is application of mirror through transmission technique using an encircling electromagnetic-acoustic (EMA) transducer [1–4]. In this case ultrasound impulse multiple reflection series of shear waves axially polarized in all radial directions over the cross section of the rod is formed. The model of acoustic wave propagation in mirror through transmission technique for cross section ellipticity testing is introduced in the paper [5]. In the case of rod cross section deviation from roundness, envelope of multiple reflections series is modulated. It is shown that envelope period and time shift of main reflection echo-impulses for an elliptical rod in comparison with a circular section rod can be used as informative parameters. This article suggests an approach to validation of new informative parameters in mirror through transmission technique for cylindrical object ellipticity testing, based on probabilistic and statistical analysis of multiple reflection series.

APPROACHES USED

The results of modeling of ultrasound wave multiple reflections in elliptical cross section rod obtained as the result of superposition of waves radiated by encircling coils EMA transducer radiating elements and received by encircling coils EMA transducer receiving elements on opposite surface with regard to ultrasound beam path in elliptical rod cross section in accordance with ray acoustic theory are used as input data for this research. Examples of modeled multiple reflection series in the rod with different ellipticity rates are represented in Fig. 1. Ellipticity Δ is defined as a half of difference between the highest d_1 and the least d_2 values of diameters in orthogonally related directions.



(a)

(b)

Figure 1. Oscillograms of multiple reflections with ellipticity Δ = 0 mm (a) and Δ = 0.25 mm (b) for the rod with diameter d = 24 mm

Such probabilistic characteristics as probability density distribution $P(x)$, dispersion Dx, root-mean-square deviation σ_x, asymmetry S_x and excess E_x were investigated to study the applicability of probabilistic characteristics as informative parameters for oscillograms represented in the form of sample sequence $\{x_n,\ n = 0,\ \ldots,\ N–1\}$. These parameters are defined by following formulas [6]:

$$P(x) = \frac{1}{N \cdot h} \cdot \sum_{n=0}^{N-1} \left(-\frac{x_m - x_n}{2h^2} \right)^2, \tag{1}$$

$$D_x = \frac{1}{N-1} \cdot \sum_{n=0}^{N-1} (x_n - m_x)^2, \tag{2}$$

$$\sigma_x = \sqrt{D_x}, \tag{3}$$

$$S_x = \frac{1}{N \cdot \sigma_x^3} \cdot \sum_{n=0}^{N-1} (x_n - m_x)^3, \tag{4}$$

$$E_x = \frac{1}{N \cdot \sigma_x^4} \cdot \sum_{n=0}^{N-1} (x_n - m_x)^4 - 3, \quad (5)$$

where N – amount of data in array x_n; $h = \sigma N^{-1/5}$; σ – root-mean-square deviation of the process; $m = 1, \ldots, M$, M – number of points in estimated probability density function.

RESULTS AND DISCUSSION

The obtained probability density distribution $P(x_m)$ is represented in Fig. 2. Different patterns of probability density are observed due to different ellipticity rates: the higher ellipticity rate, the sharper distribution peak.

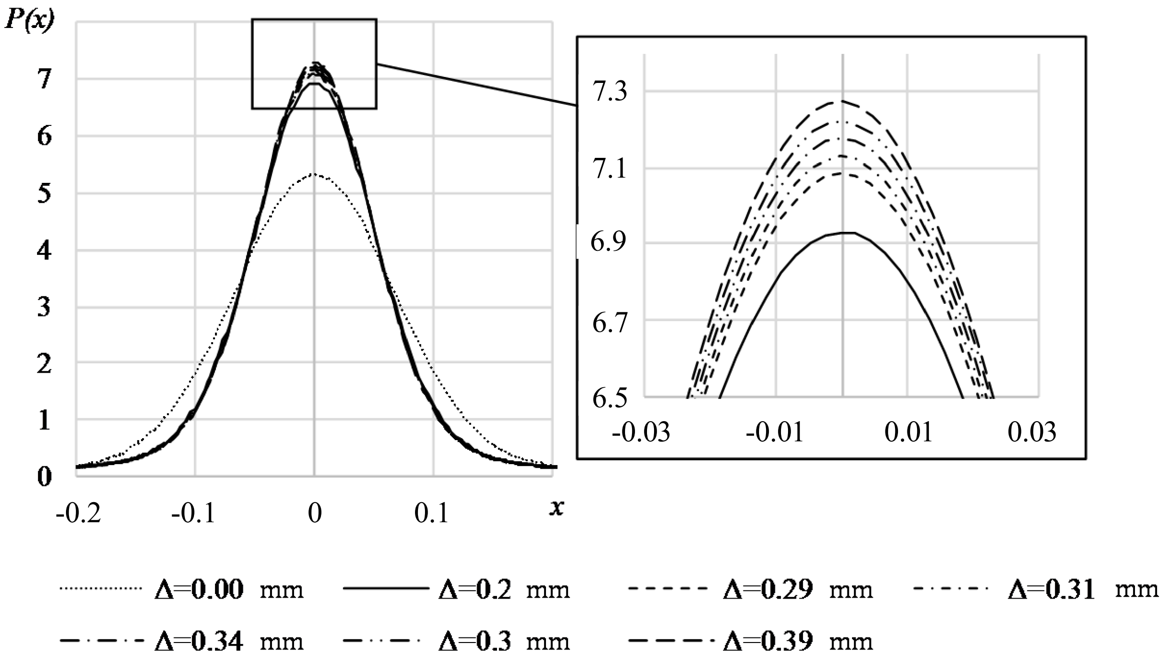


Figure 2. Probability density distribution $P(x)$ with different ellipticity rates Δ for the rod with diameter d = 17 mm

Probabilistic and statistical analysis of the given oscillograms was made in special-purpose software suite WinPOS Professinal, which is intended for post experimental measurement data processing by means of standard mathematical and statistical algorithms, study of dynamic and slowly changing processes, graphical representation and documenting of the data [7].

The dependence of oscillogram probabilistic characteristics on ellipticity Δ for the rod with diameter d = 24 mm is represented in Fig. 3. It is obvious that all presented probabilistic characteristics have evident non-linear dependences on ellipticity. Ellipticity increase causes decrease of such characteristics as dispersion and root-mean-square deviation. In particular, ellipticity Δ = 0.5 mm causes decrease of parameter "dispersion" D_x by 60 % and parameter «root-mean-square deviation» σ_x by 37 %. Excess and asymmetry, on the contrary, increase with increase of cross section ellipticity. Thus, ellipticity Δ = 0.5 mm for the rod with diameter d = 24 mm causes increase of parameter "asymmetry" S_x by 46 % and parameter "excess" E_x by 108 %.

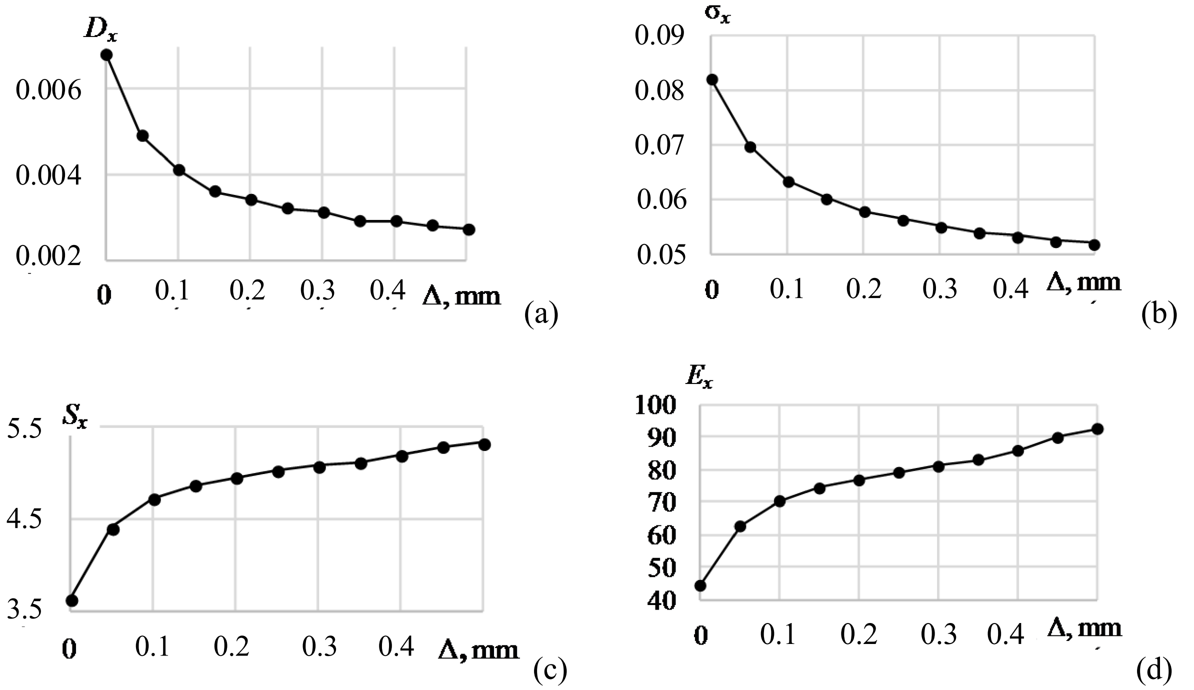


Figure 3. Dependences of dispersion D_x (a), asymmetry S_x (b), root-mean-square deviation σ_x (c), excess E_x (d) on ellipticity Δ for the rod with diameter d = 24 mm

Conclusion

In sum, developed approach allows to validate informative characteristics of signal in multiple mirror through transmission technique for cylindrical object ellipticity testing and to formulate rejection criterion for ellipticity testing of cylindrical objects with any diameters using probabilistic and statistical analysis.

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