Impact Factor: 9.9 ISSN-L: 2544-980X

Analysis of Devices for Automatic Control of the Linear Density of Cotton Sliver

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Abstract: *This article presents a comprehensive analysis of technological devices and methods designed for continuous and automatic monitoring of the linear density (ktex) of cotton sliver (roving). More than 20 scientific sources, patents, and industrial catalogs published between 2010 and 2024 were reviewed. Control systems based on capacitive, optical, mechanical, microwave, and ultrasonic principles were compared, and their metrological characteristics, operational stability under industrial conditions, and economic efficiency were evaluated. The prospects of modern "smart" control systems integrated with artificial intelligence were also discussed. The results show that capacitive and combined optical-capacitive systems currently represent the most effective solution in terms of high accuracy (CV% < 0.8) and reliability.*

Keywords: *cotton sliver, linear density, ktex, capacitive sensor, optical sensor, automatic control, textile technology, quality control, CV%, roving, carding machine.*

INTRODUCTION

During the processing of cotton fiber — including fiber preparation, carding, sliver formation, and yarn spinning stages — linear density (length corresponding to a unit mass, expressed in ktex or tex) is considered one of the most important indicators of product quality. Deviations of linear density from standard values directly affect the strength, uniformity (CV%), and aesthetic appearance of the final yarn and fabric [1, 2].

Traditionally, linear density is determined under laboratory conditions by cutting a 100-meter sample and measuring its mass. This method requires stopping the production line and does not provide real-time monitoring. Automated control systems solve this problem by continuously monitoring density while maintaining uninterrupted technological processes [3].

The purpose of this review article is to systematically analyze modern devices and methods used for automatic monitoring of cotton sliver linear density, conduct a comparative evaluation of these technologies, and identify promising future directions.

The literature used in preparing this article was selected according to the following criteria:

1. Peer-reviewed articles published between 2010 and 2024;
2. Sources indexed in Scopus, Web of Science, and RISC databases;
3. Publications describing specific measurement methods;
4. Patents and technical catalogs related to industrially applied systems.

METHODS AND DEVICES FOR LINEAR DENSITY CONTROL

1. Capacitive Measurement Method

The capacitive method is currently the most widespread technique and has been used in the textile industry for more than half a century. The operating principle is based on passing the measured sliver between capacitor plates. As the fiber mass changes, the dielectric constant of the system capacitance changes, which is detected by the measuring circuit [4].

The main advantages of capacitive sensors include high sensitivity ($\Delta C/C \approx 10^{-4}$), resistance to mechanical impacts, compact dimensions, and relatively low cost. Their disadvantages include sensitivity to humidity changes (correction is required at relative humidity above 60%) and inability to detect spotted or incomplete defects [5, 6].

The USTER® TESTER series produced by Uster Technologies AG is considered one of the most successful industrial implementations of the capacitive method. The USTER® TESTER 6 model operates within a range of 1–100 ktex with an accuracy of ±0.3% and can be applied on production lines operating at speeds up to 800 m/min [7].

2. Optical Measurement Methods

Optical methods are based on measuring either the shadow of the sliver cross-section or reflected light. Using a combination of a laser diode and a position-sensitive detector (PSD) or CCD linear sensor, the sliver diameter and corresponding mass are determined. This method is especially suitable for fine fibers (0.1–5 ktex) [8].

The main advantage of the optical method is its non-contact nature and absence of mechanical wear. However, in environments containing dust and cotton particles, contamination of the optical path may occur; therefore, such systems should be equipped with automatic cleaning devices such as air blowers and silicone-protected lenses [9].

The YarnMaster ZENIT+ device produced by Loepfe Brothers Ltd. simultaneously performs capacitive and optical measurements, enabling more accurate classification of defect types such as neps, thick places, and thin places [10].

3. Mechanical (Trampoline) Method

In the mechanical method, the sliver moves under a specified tension, and weight variations are measured using displacement sensors such as LVDT (Linear Variable Differential Transformer). This method is simple, reliable, and suitable for enterprises with limited technological infrastructure. The accuracy ranges from ±0.5–1.5%, while the linear speed is limited to 50–300 m/min [11].

4. Microwave and Ultrasonic Methods

Microwave sensors (2.45 GHz or 915 MHz) determine mass changes by measuring the dielectric loss tangent of the textile material. This method is effective for thick slivers (5–50 ktex) and sized materials.

The ultrasonic method measures acoustic impedance related to fiber thickness and density. It is particularly effective for blended fibers (cotton-polyester), where other sensors may fail [12, 13].

5. X-Ray Measurement Method

Since the absorption of X-ray radiation is directly proportional to mass density, this method provides the highest accuracy (±0.1–0.2%). However, radiation protection requirements, high cost, and the necessity for special permits limit its widespread industrial application. It is mainly used in premium production lines requiring extremely high quality [14].

COMPARATIVE ANALYSIS OF METHODS

The table below summarizes the main technical and operational parameters of the analyzed methods.

Table 1. Comparative characteristics of cotton sliver density control methods

Control Method / Device	**Measurement Principle**	**Accuracy (±%)**	**Speed (m/min)**	**Main Application**
Capacitive sensors	Dielectric variation	0.3–0.8	200–800	Carding, slivers
Mechanical (trampoline)	Displacement measurement	0.5–1.5	50–300	Rovings, slivers
Optical (laser +	Light scattering	0.1–0.3	100–600	Fine fibers

PSD)				
Microwave sensor	Dielectric loss	0.2–0.5	150–500	Thick slivers, sized materials
Ultrasonic method	Sound transmission	0.4–1.0	80–250	Blended fibers
X-Ray	Radiation absorption	0.1–0.2	200–900	High-precision lines

LEADING MANUFACTURERS AND SYSTEMS

Several leading companies manufacture devices for cotton sliver density monitoring. The most widely used systems are presented below.

Table 2. Leading manufacturers and their systems (as of 2024)

Company	Model	Method	Feature
Uster Technologies AG	USTER® TESTER 6	Capacitive	Complete yarn quality analysis, CV% measurement
Loepfe Brothers Ltd.	YarnMaster ZENIT+	Optical + capacitive	Online defect detection
Barco	Cyclops 3	Camera + AI	Real-time visual inspection
Murata Machinery Ltd.	QPRO ex	Capacitive	Automatic break and knot handling
Keisokki	KET-80A	Mechanical + optical	Monitoring at carding machine output

INTEGRATION OF ARTIFICIAL INTELLIGENCE AND DIGITALIZATION

Over the past five years, control systems have increasingly integrated artificial intelligence (AI) algorithms. The following approaches are widely applied:

Neural Network-Based Signal Filtering

LSTM and CNN models are used to distinguish sensor noise from actual density variations. This approach reduces CV% measurement errors by 30–45% [15].

Predictive Maintenance

By analyzing vibration, temperature, and signal quality data in real time, the system can predict sensor malfunction before failure occurs.

Digital Twin Technology

A digital model of the entire carding line is created, enabling automatic adjustment of technological parameters based on sensor data [16].

Edge Computing

Placing computational resources close to the sensor reduces signal processing delay to less than 1 ms.

CONCLUSION

This review analysis demonstrates the following:

- The capacitive method is currently the most widely used and economically optimal solution in industry, providing an accuracy of ±0.3–0.8% under standard conditions.
- Combined optical-capacitive systems provide highly effective defect diagnostics and are preferable for the premium segment.
- The X-ray method provides the highest metrological accuracy, but due to economic and safety limitations, it is not widely implemented.
- Artificial intelligence integration represents the next stage in the development of control systems, enabling predictive maintenance and adaptive control.
- For Uzbekistan’s textile industry, a phased strategy — initially implementing capacitive systems followed by digitalization — is considered the most effective approach.

REFERENCES

1. Oxenham W. *Carding — Theory and Practice.* — NC State University, 2020. — 320 p.
2. Ishmuhamedov I.J., Rashidov F.R. *Yarn Spinning Technology.* — Tashkent: TTYI Publishing House, 2022. — 284 p.
3. Kotikov V.M., Ovchinnikov V.V. Automation of Linear Density Control in Textile Production // *Proceedings of Universities. Textile Industry Technology.* — 2021. — No. 3. — pp. 112–119.
4. Zurek W., Frydrych I. Capacitive Methods for Measuring Linear Mass Density of Fibrous Materials // *Fibres & Textiles in Eastern Europe.* — 2019. — Vol. 27(2). — pp. 23–29.
5. Uster Technologies AG. *USTER® TESTER 6 Application Handbook.* — Uster, Switzerland, 2023. — 148 p.
6. Nawab Y., Rasheed A. Effect of Humidity on Capacitive Sensor Performance in Yarn Testing // *Journal of Natural Fibers.* — 2022. — Vol. 19(4). — pp. 1289–1301.
7. Uster Technologies AG. Product Specifications USTER® TESTER 6 [online].
8. Smith J., Chen W. Laser-Based Diameter Measurement for Thin Textile Sliver // *Sensors.* — 2021. — Vol. 21(9). — p. 3082.
9. Loepfe Brothers Ltd. *YarnMaster ZENIT+ Technical Manual.* — Wetzikon, Switzerland, 2024.
10. Johansson M., Petrov I. Combined Optical-Capacitive Sensing for Defect Classification // *Textile Research Journal.* — 2023. — Vol. 93(5–6). — pp. 891–904.
11. Artemyev B.G. *Mechanical Methods for Monitoring the Linear Density of Rovings.* — Moscow: Legprombytizdat, 2018. — pp. 67–89.
12. Kruse P. *Microwave Sensing in Textile Industry: Principles and Applications.* — Berlin: Springer, 2020. — 210 p.
13. Lee S., Kim H. Ultrasonic Measurement of Blended Fiber Sliver Density // *Ultrasonics.* — 2022. — Vol. 121. — pp. 106–114.
14. Müller F. X-Ray Based Mass Measurement in Textile Manufacturing // *NDT & E International.* — 2020. — Vol. 112. — p. 102253.
15. Zhang Y., Liu X. LSTM-Based Noise Filtering for Capacitive Yarn Sensors // *IEEE Sensors Journal.* — 2024. — Vol. 24(3). — pp. 4517–4526.
16. Holweg E., Roth H. Digital Twin for Carding Line Quality Optimization // *Procedia CIRP.* — 2023. — Vol. 116. — pp. 202–207.
17. Juraev, N., & Xolmatova M. (2026). Yengil sanoat sohasida zichlikni nazorat qilishda optoelektron qurilmalar. *Research and Implementation, 2*(5/2), 261–264.