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IMPROVING PRODUCT QUALITY BY ENSURING WARP YARN TENSION STABILITY IN THE WEAVING PROCESS

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Abstract:
This study presents the development and evaluation of an additional mechanism aimed at improving fabric quality by stabilizing warp yarn tension in weaving machines. Uneven and unstable warp tension is one of the major factors negatively affecting fabric strength and increasing yarn breakages during weaving. To address this issue, a flexible-cylinder-based device was designed, in which the wrapping arc length of the warp yarn wound along the cylinder's perimeter can be adjusted depending on shed volume, weave type, and the process of beating the weft yarns to the fabric edge. This adjustment allows the creation of uniform warp yarn tension throughout the shed formation process.
Experimental validation was conducted using fabric samples tested on a YG026T tensile testing machine under half-cycle loading conditions. The results revealed that the proposed mechanism not only reduced yarn breakages but also enhanced the structural integrity and overall quality of the woven fabric. Furthermore, it was observed that the device contributed

to more uniform fiber distribution and alignment, leading to improved mechanical performance of the fabric.

The findings demonstrate that ensuring warp yarn tension stability is a critical factor in increasing weaving efficiency and fabric durability. The proposed mechanism provides a practical and effective solution for modern weaving processes, with the potential to be widely implemented in textile manufacturing to produce high-quality and competitive fabrics.

Keywords: Warp yarn tension, weaving process, fabric quality, yarn breakages, flexible cylinder, tensile testing, weaving efficiency, fabric durability.

INTRODUCTION

The textile industry is one of the fastest-growing industries in the world, with modern technologies being applied across various sectors. In particular, special attention is given to improving product quality indicators and producing a new range of competitive products through the introduction of nanotechnology, artificial intelligence, high-precision devices, and the latest achievements in electronics. According to Wazir Management Consulting [1], the global demand for textile products is expected to reach **USD 2 trillion** by 2025. Currently, the market value stands at **USD 1.1 trillion**, which means there will be an additional demand for nearly **USD 1 trillion** worth of products.

This growing demand is expected to be more significant in certain regions where the need for textile raw materials is increasing, such as China, India, Brazil, and Russia. To meet this demand, both developed and developing countries are focusing on intensive industrialization and the integration of innovative technologies into the textile industry. This includes the proper adjustment of weaving machine technological parameters, automation, simplified and user-friendly control systems, artificial intelligence–based management, and the development of high-efficiency, energy-saving, and environmentally friendly technologies, all aimed at improving the quality of manufactured products.

Furthermore, in Uzbekistan, wide-ranging measures are being implemented to increase the investment attractiveness and competitiveness of the textile and apparel industry, to expand its export potential, and to create favorable conditions for the broader entry of domestic textile products into foreign markets. For this purpose, the Presidential Decree of the Republic of Uzbekistan No. PF-71, dated 01.05.2024, was adopted. [2]

In our country, large-scale efforts are being carried out to rapidly develop the textile industry, expand the range of finished and semi-finished products, introduce new innovative technologies, and increase the export potential of textile enterprises. The “Uzbekistan – 2030” Strategy [3] outlines specific tasks, such as “developing the driver sectors of the economy and fully utilizing the industrial potential of the regions, creating national brands for finished products and increasing their exports, including aligning the quality of textile products with international standards and ensuring their advancement to leading positions in the global market.”

In order to achieve these objectives, scientific research plays an important role, particularly in determining the dynamics of changes in the physical and mechanical properties of fabrics, identifying the full extensibility characteristics of warp yarns, designing devices to control warp yarn tension in weaving machines, and developing kinematic schemes of mechanisms that regulate warp yarn supply and tension. Such research is crucial to ensuring product quality and durability in textile manufacturing.

Materials and Methods

In this study, an additional mechanism was designed and installed on weaving machines to stabilize warp yarn tension, with the aim of improving fabric quality and reducing yarn breakages. The research methodology included both the development of the device and the experimental evaluation of its effectiveness.

Device function. The main function of the mechanism is to maintain uniform warp yarn tension during the process of shed formation. This is achieved by altering the wrapping arc length of the warp yarn wound around the perimeter surface of a flexible cylinder. The adjustment is carried out according to shed volume, weave type, and the beating-up of the weft yarns to the fabric edge. As a result, the device compensates for variations in tension, thereby reducing uneven stress distribution in the warp yarns.

Device operation. Structurally, the mechanism consists of a fixed roller and a flexible cylinder mounted on a common rotational axis. The flexible cylinder, fabricated from thin steel plates, has a larger perimeter than the roller, which creates a semi-uniform gap between the two components. This gap functions as a compensator, dynamically altering the arc length of the warp yarn. Consequently, the overall tension value is regulated and stabilized, which directly impacts the uniformity of the yarn tension during weaving.

Experimental procedure. For validation, fabric samples produced using the modified weaving machine were tested on a YG026T electronic fabric tester employing the half-cycle tensile method. A fabric specimen measuring 100 × 250 cm was prepared, from which 10 strips each of 300 × 50 mm were cut in both warp and weft directions. The samples were subjected to tensile testing until rupture, and parameters such as breaking force, elongation, and relative breaking force were recorded.

This methodological approach allowed for a comparative analysis of fabric strength and yarn breakage before and after the installation of the tension-regulating mechanism, thereby providing experimental evidence of its effectiveness.

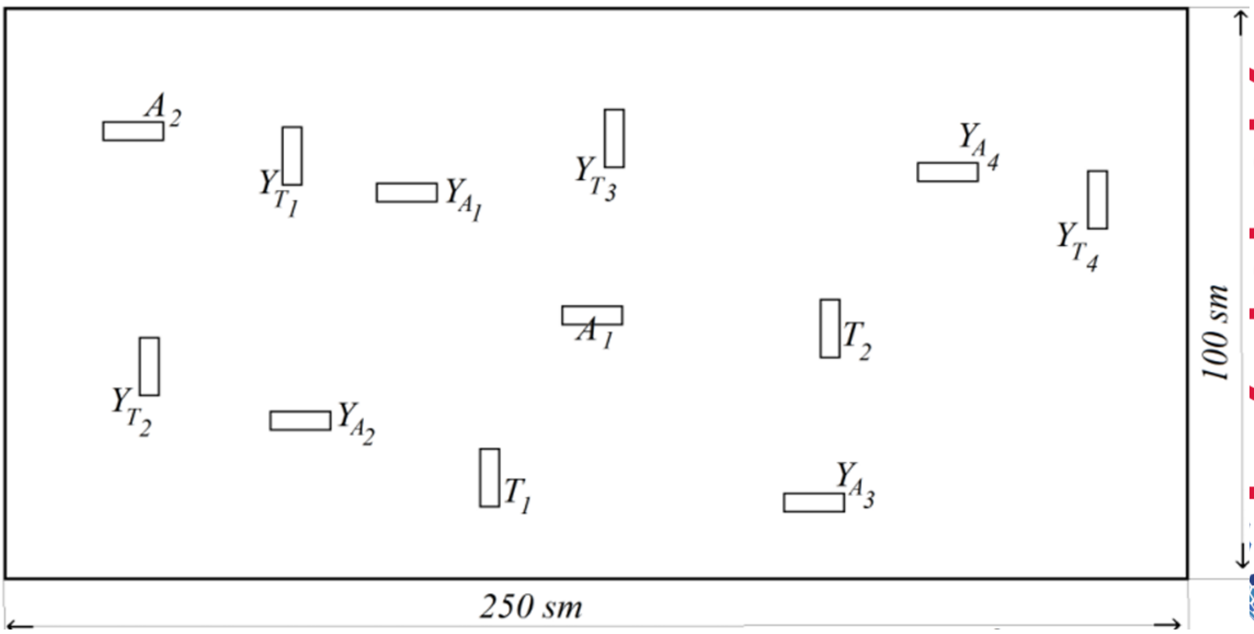

Figure 1. Cutting scheme of the fabric specimen prepared for tensile testing. The samples were stretched on the laboratory device until rupture..

Figure 2. Condition of the fabric specimens after rupture. [4]

The experimental tests were conducted to evaluate the impact of the newly designed compensator mechanism on the mechanical properties of woven fabrics. A series of tensile tests were performed on fabric specimens in both the warp and weft directions using a YG026T electronic fabric tester. The main parameters measured included:

- **Breaking force (N)** – the maximum force applied before rupture,
- **Elongation at break (mm)** – the extension of the fabric sample at rupture,
- **Relative breaking force (N/Tex)** – normalized breaking strength relative to yarn fineness,
- **Time to rupture (s)** – duration until failure under load,
- **Work of rupture (N·mm)** – energy absorbed by the fabric before breaking.

The obtained results were presented in both tabular and graphical forms for comparative analysis. Tables **1a** and **1b** summarize the mechanical characteristics of samples tested in the **weft and warp directions**, respectively, before the installation of the warp tension–regulating compensator. These baseline measurements represent the performance of fabrics produced under conventional weaving conditions without additional regulation of warp tension.

The analysis of the data revealed significant variability in the measured parameters, particularly in breaking force and elongation, which indicates unstable warp tension during the weaving process. This variability contributes to uneven yarn loading, leading to premature yarn breakages and reduced overall fabric quality.

Subsequent results, obtained after installing the compensator mechanism (Tables 2a and 2b, discussed in the following section), were compared with these baseline values. The comparison allowed for a clear evaluation of the effectiveness of the device in stabilizing warp yarn tension and improving fabric durability.

Table 1a. Tensile strength test results of fabric samples in the weft direction under conventional weaving conditions (without compensator).

№	Break Force (N)	Elongate (mm)	Elong Rate (%)	Break strength (N/Tex)	Work (N*mm)	Time (sec)
1	200	17.70	8.85	4.00	1267.00	10.62
2	196	18.10	9.05	3.92	1291.20	10.86
3	238	20.10	10.05	4.76	1780.70	12.06
4	260	19.80	9.90	5.20	2030.50	11.88
5	240	20.70	10.35	4.80	1826.70	12.42
6	231	19.80	9.90	4.62	1668.90	11.88
7	233	19.50	9.75	4.66	1778.90	11.70
8	220	18.90	9.45	4.40	1532.60	11.34
9	225	19.10	9.55	4.50	1532.80	11.46
10	250	20.70	10.35	5.00	1956.10	12.42
medium	229.30	19.44	9.72	4.59	1666.54	11.66
Max	260.00	20.70	10.35	5.20	2030.50	12.42
Min	196.00	17.70	8.85	3.92	1267.00	10.62
CV	8.78	5.17	5.17	8.78	15.54	5.17

Table 1b. Tensile strength test results of fabric samples in the warp direction under conventional weaving conditions (without compensator).

№	Break Force (N)	Elongate (mm)	Elong Rate (%)	Break strength (N/Tex)	Work (N*mm)	Time (sec)
1	290	22.30	11.15	5.80	2100.40	13.38
2	283	22.80	11.40	5.66	2117.70	13.68
3	275	21.60	10.80	5.50	1973.80	12.96
4	292	23.70	11.85	5.84	2171.60	14.22
5	278	24.00	12.00	5.56	2079.20	14.40
6	312	24.10	12.05	6.24	2480.20	14.46
7	309	25.00	12.50	6.18	2475.80	15.00
8	253	21.60	10.80	5.06	1741.60	12.96
9	293	23.30	11.65	5.86	2166.10	13.98
10	251	20.20	10.10	5.02	1623.30	12.12
medium	283.60	22.86	11.43	5.67	2092.97	13.72
Max	312.00	25.00	12.50	6.24	2480.20	15.00
Min	251.00	20.20	10.10	5.02	1623.30	12.12
CV	7.20	6.34	6.34	7.20	13.01	6.34

Analysis of Table 1a and Table 1b Results. The results presented in Tables 1a and 1b illustrate the tensile strength characteristics of fabric samples in the **weft** and **warp** directions, respectively, under conventional weaving conditions without the use of the compensator mechanism.

- In the **weft direction** (Table 1a), the average breaking force was **229.3 N**, with elongation values around **19.44 mm (9.72%)**. The relative breaking force averaged **4.59 N/Tex**, while the work of rupture reached **1666.54 N·mm**. However, the coefficient of variation (CV) for breaking force was **8.78%**, indicating noticeable variability and instability in yarn tension distribution.
- In the **warp direction** (Table 1b), the fabric samples demonstrated higher performance values. The average breaking force increased to **283.6 N**, while elongation was **22.86 mm (11.43%)**. The relative breaking force averaged **5.67 N/Tex**, and the work of rupture reached **2092.97 N·mm**. Compared to the weft direction, the warp samples absorbed more energy before rupture, showing better load-bearing capacity.

Comparative observations:

- The warp direction showed **~24% higher breaking force** than the weft direction.
- Elongation and relative breaking force were also consistently higher in the warp direction.
- Despite these differences, both directions exhibited a certain degree of variability, confirming that uneven warp yarn tension during weaving contributed to instability in fabric performance. These baseline results highlight the limitations of weaving without a warp tension–stabilizing device. The relatively high variability and lower strength in the weft direction emphasize the need for improved tension control mechanisms. The subsequent results (Tables 2a and 2b) after installing the compensator are expected to demonstrate reduced variability and enhanced mechanical performance, thus validating the effectiveness of the proposed mechanism.

Tables 2a and 2b present the laboratory test results of fabric samples cut in the weft and warp directions, respectively, after installing the warp tension–regulating compensator on the weaving machine.

Table 2a. Tensile strength test results of fabric samples in the warp direction after installing the compensator.

№	Break Force (N)	Elongate (mm)	Elong Rate (%)	Break strength (N/Tex)	Work (N*mm)	Time (sec)
1	324	26.60	13.30	6.48	2639.50	15.96
2	318	27.20	13.60	6.36	2622.20	16.32
3	325	27.00	13.50	6.50	2662.90	16.20
4	339	26.30	13.15	6.78	2825.10	15.78
5	321	25.20	12.60	6.42	2568.20	15.12
6	328	24.40	12.20	6.56	2512.60	14.64
7	328	24.90	12.45	6.56	2734.50	14.94
8	268	23.10	11.55	5.36	1843.70	13.86
9	321	25.70	12.85	6.42	2502.80	15.42
10	346	26.70	13.35	6.92	2946.70	16.02
medium	321.80	12.86	12.86	6.44	2585.82	15.43
Max	346.00	13.60	13.60	6.92	2946.70	16.32
Min	268.00	11.55	11.55	5.36	1843.70	13.86
CV	6.46	5.10	5.10	6.46	11.41	5.10

Table 2b. Tensile strength test results of fabric samples in the weft direction after installing the compensator.[5;6]

№	Break Force (N)	Elongate (mm)	Elong Rate (%)	Break strength (N/Tex)	Work (N*mm)	Time (sec)
1	230	19.30	9.65	4.60	1663.50	11.58
2	195	17.50	8.75	3.90	1343.10	10.50
3	215	19.00	9.50	4.30	1548.50	11.40
4	238	18.70	9.35	4.76	1745.60	11.22
5	262	19.60	9.80	5.24	1991.20	11.76
6	249	19.10	9.55	4.98	1881.00	11.46
7	253	19.60	9.80	5.06	1966.60	11.76
8	243	18.70	9.35	4.86	1836.30	11.22
9	249	18.90	9.45	4.98	1871.60	11.34
10	259	18.90	9.45	5.18	2001.80	11.34
medium	239.30	18.93	9.47	4.79	1784.92	11.36
Max	262.00	19.60	9.80	5.24	2001.80	11.76
Min	195.00	17.50	8.75	2.90	1343.10	10.50
CV	8.74	3.16	3.16	8.74	11.95	3.16

Analysis of Table 2a and Table 2b Results. Tables 2a and 2b summarize the tensile strength characteristics of fabric samples in the **warp** and **weft** directions, respectively, after installing the warp tension–regulating compensator on the weaving machine.

- In the **warp direction** (Table 2a), the average breaking force increased to **321.8 N**, compared to **283.6 N** in the baseline condition (Table 1b). Elongation values also improved, reaching **12.86%**, while the relative breaking force averaged **6.44 N/Tex**. The work of rupture rose significantly to **2585.82 N·mm**, indicating higher energy absorption capacity and greater durability. The coefficient of variation (CV) values decreased, reflecting more stable and uniform yarn tension.
- In the **weft direction** (Table 2b), the average breaking force reached **239.3 N**, slightly higher than the baseline value of **229.3 N** (Table 1a). Elongation values remained around **9.47%**, while the relative breaking force improved to **4.79 N/Tex**. The work of rupture increased to **1784.92 N·mm**, suggesting improved fabric toughness and resistance to rupture.

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Comparative discussion: After installing the compensator, the **warp direction showed the most significant improvement**, with breaking force increasing by approximately **13.5%** and rupture energy by nearly **24%**.

- In the **weft direction**, improvements were more modest but still notable, with an increase in breaking force of about **4.4%** and rupture energy by **7%**.
- The reduction in CV values in both directions demonstrates that the compensator effectively minimized tension fluctuations, leading to more uniform fabric properties.

Key outcome: The results clearly indicate that the compensator mechanism successfully stabilized warp yarn tension, thereby enhancing fabric mechanical performance. The improvements were especially evident in the warp direction, where yarn tension instability is typically most critical. This confirms the practical effectiveness of the proposed device in increasing fabric quality and durability in industrial weaving applications.
Based on the above tables, a histogram was constructed only for the warp yarn direction.
In this histogram (figure 1), the fabric strength results in the warp direction are compared under two conditions.

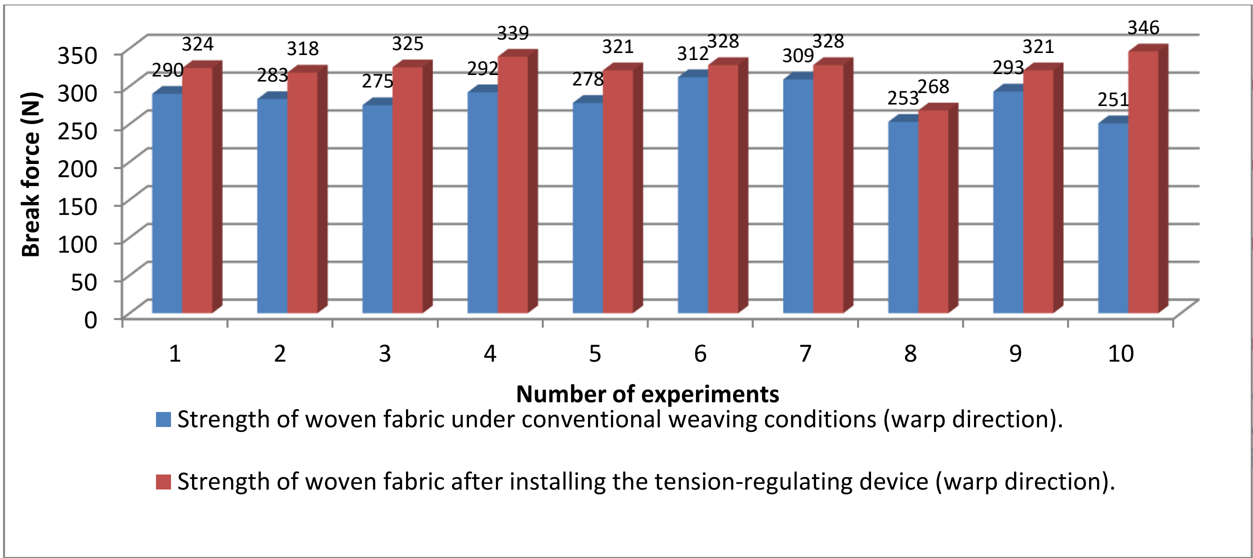

Figure 1. Comparison of fabric strength in the warp direction under two conditions: (1) conventional weaving and (2) weaving with the tension-regulating device installed.

The results demonstrate that fabric strength consistently increased after the installation of the device. On average, the strength improvement ranged between **30–90 N**, corresponding to a **10–30% enhancement** compared to conventional weaving. The most significant differences were observed in the 8th and 10th trials, confirming the effectiveness of the compensator in stabilizing warp yarn tension and improving fabric durability.

Conclusion

This study provided a comprehensive analysis of the role of deformation properties in determining the quality of woven fabrics and evaluated the effectiveness of a newly developed device designed to stabilize warp yarn tension during weaving. The experimental results clearly showed that the compensator mechanism significantly improved fabric strength, reduced yarn breakages, and enhanced the uniformity of warp yarn tension. On average, fabric strength increased by 10–30%, demonstrating the direct positive impact of the device on the durability and performance of woven fabrics.

The findings confirm that deformation characteristics such as elasticity, extensibility, and plasticity of yarns are critical parameters influencing both the efficiency of weaving processes and the quality of the final product. Instability in warp yarn tension leads to non-uniform stress distribution, higher breakage rates, and lower mechanical performance of fabrics. By contrast, the application of the proposed tension-regulating device ensured stable yarn behavior, contributing to improved structural integrity and more consistent fabric properties.

From an industrial perspective, the implementation of such mechanisms in modern weaving machines can provide several advantages:

1. **Improved fabric quality** – higher tensile strength and durability;
2. **Reduced production losses** – fewer yarn breakages and machine stoppages;
3. **Enhanced efficiency** – more stable weaving performance and lower variability in product quality;
4. **Competitiveness** – the ability to produce fabrics that meet international standards and respond to the growing global demand for high-quality textiles.

In addition, the study emphasizes the importance of further research on the dynamic behavior of yarn deformation properties at different technological stages. A deeper understanding of how elasticity, extensibility, and plasticity evolve during weaving will enable the design of more advanced mechanisms, intelligent control systems, and energy-efficient technologies for the textile industry.

Overall, the proposed device represents a practical and effective solution for stabilizing warp yarn tension and can serve as a valuable innovation for textile enterprises aiming to improve fabric quality, increase production efficiency, and strengthen their position in the global market.

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