ISSN 2181-8622

Manufacturing technology problems

Scientific and Technical Journal Namangan Institute of Engineering and Technology

NAMANGAN MUXANDISLIK-TEXNOLOGIYA INSTITUTI

INDEX COPERNICUS INTERNATIONAL

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Volume 10
Issue 4
2025

THEORETICAL STUDY AND CHARACTERISTICS OF YARNS IN THE PRODUCTION OF CIRCULAR KNIT FABRICS

SOLIYEV AZIZBEK

Associate Professor, Namangan State Technical University, Namangan, Uzbekistan
Phone.: (0588) 860-5656, e-mail.: azizbek_0789@mail.ru

Abstract: The article analyzes the properties of yarns used in circular knit fabrics, which are currently in high demand, as well as the research conducted by scientists in this field. Based on these analyses, conclusions were drawn regarding the investigation of the deformational properties of yarns for the production of circular knit fabrics and the mathematical modeling of yarn as a solid body.

Keywords: loop, yarn, deformation, model, dynamics, force, discrete.

Introduction. Globally, the textile industry is one of the fastest-growing sectors, with modern technologies being implemented across various branches of the industry. Particular attention is paid to improving product quality indicators and producing competitive products in new assortments through the introduction of nanotechnology, artificial intelligence, high-precision equipment, and the latest advances in electronics.

In our country, extensive efforts are being made to rapidly develop the textile industry, expand the range of produced finished and semi-finished products, implement new innovative technologies, and enhance the export potential of textile enterprises.

In the textile industry, improving product quality is closely associated with the optimization of technological processes. In particular, the deformational properties of yarns and fabrics during the knitting process are key factors that determine process efficiency and the quality of the final product. These deformational properties vary at different stages of the technological process and manifest through parameters such as yarn flexibility, elongation, and elasticity during knitting. Consequently, they affect the strength, appearance, and usability of the product [1].

In our study, we investigate the deformational behavior of yarns used in circular knit products, which currently constitute a significant portion of domestically produced and export-oriented goods. These products include various towels, table linens, upholstery for furniture, decorative items, robes, and similar items.

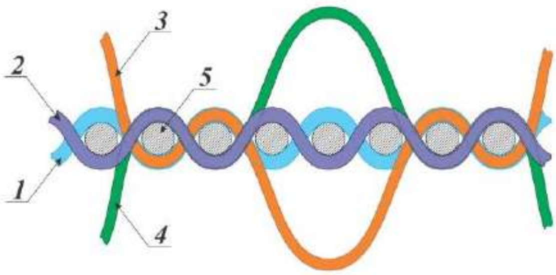

Figure 1. Arrangement of yarns in circular knit fabric: 1, 2 – ground pile yarns; 3, 4 – loop pile yarns; 5 – guide yarns.

Circular knit fabric is formed as a result of the interlacing of ground, pile, and guide yarns (Figure 1). Circular knit fabrics can generally be single- or double-knit and may feature patterns on the fabric surface (Figure 2).

Figure 2. Circular knit fabric and products

The development of the global textile industry has been studied over the years through scientific research. However, the increasing use of towels and circular knit fabrics in daily life indicates that several challenges remain in this area.

The knitting process is a complex procedure in which pile and guide yarns are interlaced under controlled tension to create a stable fabric structure.

Knitting machines operate under complex mechanical dynamics, where yarn tension plays a crucial role in determining fabric quality, machine efficiency, and operational stability. Understanding how yarns deform under tension is essential for controlling the properties of the knitted fabrics.

The properties and performance of pile fabrics are largely determined by the characteristics of the yarn. Different technologies used in yarn production result in various fiber compositions, allowing for the manufacture of different types of yarns. Additionally, other methods are employed to modify yarn structure, which can positively influence the properties and usability of pile fabrics. These technological processes include alterations in pile density, capillarity, and fiber volume.

The use of mathematical models to predict yarn deformation behavior and its response to process conditions has demonstrated significant potential for reducing product defects and optimizing technological processes. At the same time, the physical and mechanical properties of yarns used in the production of pile fabrics—particularly the dependence of yarn stiffness coefficients on their testing lengths—remain insufficiently studied. This issue affects critical aspects such as needle bed dimensions, pile yarn tension in knitting machines, and the optimization of knitting parameters.

Deformation is the change in shape and size of a body under the influence of external forces. It can be elastic or plastic: if the deformation disappears after the external force is removed (the body returns to its original state), it is elastic deformation; if it remains (the body does not return to its original state), it is plastic deformation. Types of deformation include tension, compression, bending, and twisting (Figure 3).

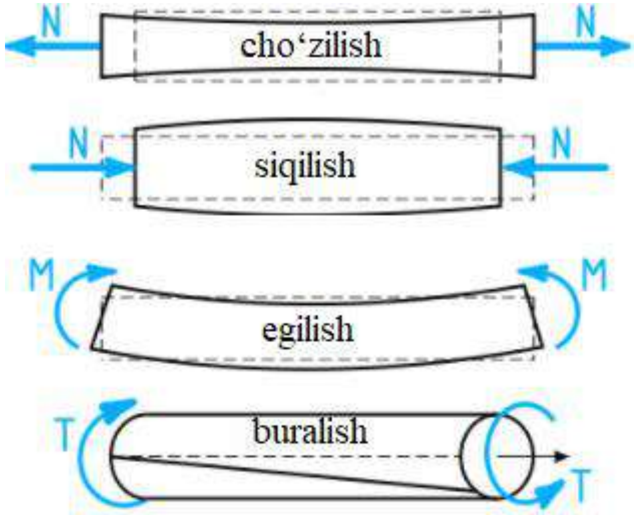

Figure 3. Types of deformation: tension, compression, bending, and twisting

Researchers studying polyester and cotton yarns under various tension levels have identified elastic deformation, emphasizing the linear stress–strain relationship within the elastic limit [2].

According to studies on the plastic deformation of high-strength synthetic yarns [3], relative stresses exceeding 70% of the ultimate strength led to plastic deformation. These investigations provided fundamental insights into the plastic deformation behavior of synthetic yarns. Determining the threshold of relative strength for deformation was found to be of significant importance.

Rahman and other researchers [4] analyzed the effects of moisture and temperature variations on the elastic and plastic deformation of cotton and silk yarns. They recommended adjusting environmental conditions to minimize deformation inconsistencies. The studies identified the influence of humidity and temperature on both elastic and plastic deformations in fibers.

Researchers examining the deformation behavior of blended yarns found that polyester–cotton blends exhibited improved elastic recovery compared to pure cotton yarns [5].

In the study of fabric formation, several investigations have explored the use of artificial intelligence to analyze yarn properties. These include: "A Geometric Feature Set-Based Neural Network for Classifying Textile Defects" [6], "Assessment of Knitted Fabric Properties Using Artificial Neural Networks" [7], and "Application of Artificial Neural Networks (ANN) to Predict Thermal Resistance of Knitted Fabrics at Various Humidity Levels" [8].

Cotton yarns are doubled with fine polyvinyl acetate (vinyl acetate or polyvinyl alcohol complex ester and acetic acid polymer) (PVA) filaments or yarns. The primary reason for using such yarns without introducing twists is to provide pile fabrics with softness and high water absorption properties. For the production of these yarns, cotton yarns are combined with PVA filaments or very fine PVA yarns. The applied twist is in the opposite direction to that of the single yarn, which untwists the main yarn and aligns the fibers nearly parallel to each other. The PVA component envelops the untwisted main yarn, providing the necessary tension. This tension is required during the knitting of the fabrics [9].

Considering the knitting process of textile fabrics, researchers [44] investigated yarn-to-yarn friction through analytical modeling and experimental validation. They identified that friction between twisted yarns, if excessive, can significantly affect the mechanical properties of reinforced composites, potentially degrading the performance of the reinforcing fibers. This makes the control of yarn friction a critical issue in the production of fabric reinforcing elements.

Abdulloh al-Farruhi has conducted scientific research focused on pile fabrics, which are increasingly in demand, examining the effects of chemical processes applied during production on the properties of the fabrics.

He highlights that in the modern textile industry, various methods are being implemented to enhance the water absorption and softness of pile fabrics. According to his conclusions, the softness of pile fabrics largely depends on the softness of the pile yarns, which in turn is influenced by two main factors: the type and characteristics of the fiber, and the number of twists in the yarn. These factors are identified as key determinants directly affecting the functional properties of pile fabrics. Furthermore, the study notes that reducing the number of twists in the pile yarns increases the water absorption and softness of pile towels [11].

In recent years, the development of science has been closely linked to computerization, which provides an objective basis for the advancement of discrete methods in mathematics and mechanics. A review of recent literature [12–21] supports the use of practical modeling of systems and processes, deformable solid mechanics, and structural mechanics via discrete modeling, establishing it as an independent direction in science.

However, in yarn mechanics theory, studies dedicated to discrete modeling are very limited. When attempting to solve such problems using computer methods, any task ultimately needs to be reduced to a discrete form.

The construction of a discrete model primarily involves two steps: first, replacing the continuous yarn with a structure composed of discrete elements, and second, describing the interactions between these discrete elements. As a result of this description, the differential equations that characterize the interactions within an infinitely small continuous filament are replaced by algebraic equations for elements of finite size.

Regardless of the chosen numerical method, constructing the discrete structure of a yarn begins with representing the real continuous yarn as a collection of interconnected discrete elements. The resulting sampled structure should geometrically resemble the actual yarn. Additionally, the model must account for the physical and mathematical properties of the yarn’s constituent components.

In general, the discrete structure only approximately reflects, that is, models, the behavior of a continuous yarn.

We assume a yarn capable of deformation under tension, bending, and twisting, possessing a spatial configuration in equilibrium or in a stationary contour under the action of external forces.

In considering yarn dynamics, the deformation properties are taken into account by accumulating internal forces at the spherical joints connecting the discrete elements of the yarn. Modeling the behavior of the discrete yarn under external loads is divided into two levels: macro and micro. At the macro level, the model should reflect the physical response of the entire yarn structure to the applied forces and moments, i.e., it should capture the change in shape and volume under deformation and determine the interconnections between individual discrete elements. At the micro level, the model should determine the internal response of the discrete structural elements to external forces. Physically, this means that the micro-level model defines the stress-strain relationships and the rheological properties of the yarn.

To visually demonstrate the physics of deformation in a discrete yarn structure, Figure 4 presents the classification of macro-level models. Representing the deformation model of transverse entanglements in a figure is challenging because it must depict dependent and normally sheared interactions, which are defined mathematically in the deformation description.

At the macro level, the deformation and shape of the entire yarn segment involved in the simulated technological process are determined as a set of elementary deformation changes of the discrete filament elements relative to each other, which are identified at the micro level.

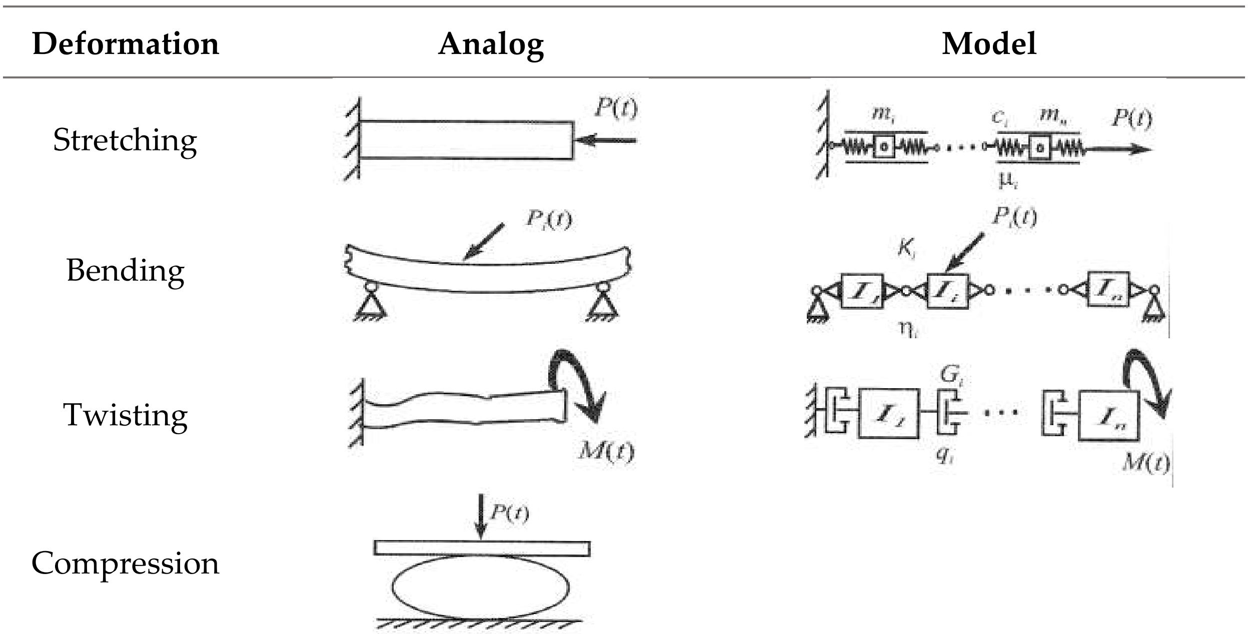

Figure 4. Classification of deformation models at the macro level

In technological process models, a yarn may simultaneously be subjected to external longitudinal and transverse forces, as well as bending and torsional moments. This leads to complex deformation behavior of the yarn.

According to [22], the relationship between stress intensity, bending and torsional strain for yarn models subjected to complex deformation at each point of the yarn cross-section is the same as the corresponding stress-strain relationships for simple stretching, bending and torsion. This provides a basis for introducing assumptions in yarn technological models that deformations are independent of complex loading of the yarn.

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