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Yarn Movement in Ring-Spun Yarn Based on Kinematics: A New Model

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Abstract

A new model to know the influence of fiber movement in Ring spun yarn to the characteristic of yarn as the twist of yarn can be derived by using analytical mechanics, especially kinematics. In this research, the relationship of a twist to spindle speed, traveler, and linear speed of yarn has been formulated theoretically and validated experimentally in the ring-spun yarn machine. Based on this research, both theoretically and experimentally, we have found a good modeling and validation relationship. This research's scientific impact is a simple new method for modeling the Ring Spun machine's yarn movement based on kinematics.

Keywords: ring spinning, twist, kinematics, yarn movement

INTRODUCTION

The application of mathematics, especially in dynamics and kinematics of yarn motion in textile science, has been widely applied by several researchers [1-5]. Spinning is forming fibers or filaments from natural materials or synthetic polymers into yarn through twisting. [1,2,3,4] In the spinning process, several spinning systems, such as open-end Spinning, ring spinning, and air-jet Spinning. [3] Spinning is a process of changing raw materials in the form of fiber into yarn with certain stages. The manufacturing process starts with opening the clump of fiber, cleaning the fiber, mixing the fiber, straightening the fiber, trapping, and stretching the fiber until giving a twist into yarn. Generally, there are two types of spinning processes, as follows: ring spinning and open-end spinning systems. According to Lawrence[4], the spinning process using the ring-spinning system is the most commonly carried out in the textile industry. Lawrence [4] states that the most crucial part of a spinning process is the type of fiber that can be spun, the spinning process's economic value, and the suitability and yield of the yarn structure. Its quality is to be used more broadly in the final result. In textile, twisting is crucial for making a continuous yarn from short discontinuous fibers, such as carbon fibers, sliver fibers, cotton, or wool. It powerfully influences the mechanical strength, rigidity, electric conductivity, and surface characteristics of the resulting yarn. Some researchers [1-8] have formulated the movement of the fibers in the yarn using an approach with mechanical modeling. The model results show pretty good results computationally with a view of classical dynamics and tensor calculus. Putra et al. [1,2] stated that the greater the value of the yarn number in Nm, the greater the twist. The twist's size will affect the yarn's strength and the tenacity of the yarn—the greater the twist, the lower the yarn strength and resistance. Research on the dynamics of fiber movement in yarns has been carried out by various researchers with various dynamics and various formulations predicting fiber and yarn movement's effect on the yarn quality properties. [1-7] According to Lawrence [4], the ring-spinning machine system has parts like Figure 1. The spun fiber material is included in the drafting system. Figure 1 shows that the Lappet is under drafting and the Ring and spindle are in the middle, with the Ring, spindle, and Lappet having the central axis coincide (coaxial). The yarn moves from drafting to lappet, then at traveler rotation, and finally to the spindle. In this research, the kinematics model's formulation of yarn motion on the ring-spinning machine will be examined without considering aspects of forces such as yarn friction, wind resistance force, and gravity force.

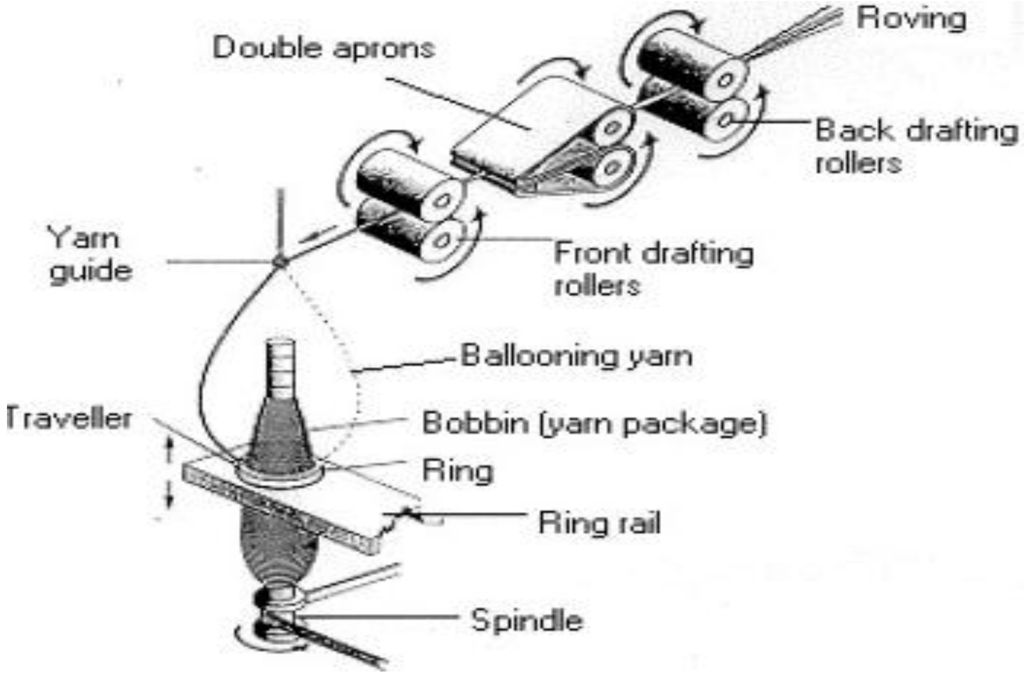

Figure 1. Ring spinning machine scheme

RESEARCH METHODS

Modeling The Difference of Yarn Twist Δ*T*

Some scientists [8-14], specifically in textiles, such as Zeidman, Shawney, and Herington [11], used mathematical models and geometric mechanics to formulate the Equations of motion of a mass material in a system of inertial reference frames. In this study, analytic mechanics, especially kinematics and calculus tensors, are used to explain the phenomenon of yarn movement in the Ring Spinning machine in the non-inertia reference frame at two-dimensional polar coordinates. Modeling the yarn's motion on the Ring Spinning machine is reviewed in a fixed frame and a frame modeled in Figure 2. It is supposed that the traveler moves with a certain angular velocity of $\dot{\phi}$ in a unit (rpm) due to the spindle rotation of $\dot{\theta}$ in a unit (rpm) and the yarn move with a twist speed of $\dot{\psi}$ in a unit (rpm) with the linear speed of the front roller on the drafting of v_f and the string of rows is r in a unit (m) with circular trajectory lines on The ring is equal to R in a unit (m), as in Figure 2, so the formulation of yarn twist can be described as follows:

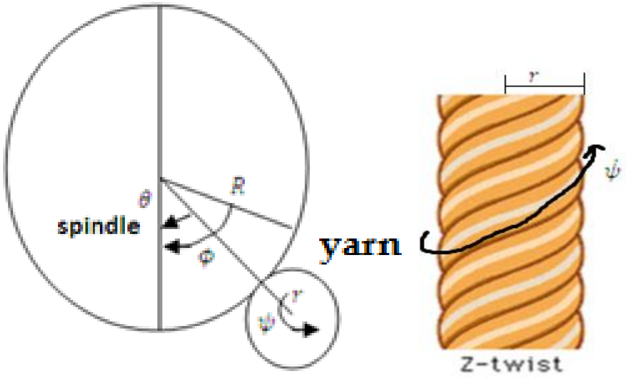

Figure 2. Modeling yarn movements

Based on Figure 2, it can be shown that the yarn moves in a frame of reference with position and speed can be formulated as in Equation (1) and Equation (2):

$$\theta(R+r) = \psi r + \phi R \tag{1}$$

$$\dot{\theta}(R+r) = \dot{\psi} r + \dot{\phi} R \tag{2}$$

When $\dot{\psi} r = v_f$ in a unit (m/min) as yarn linear speed, hence we can formulate as Equation (3) and Equation (4)

$$\dot{\theta}(R+r) = v_f + \dot{\phi} R \tag{3}$$

$$v_f = \dot{\theta}(R+r) - \dot{\phi} R \tag{4}$$

with a high spindle rotation speed for one full rotation can be formulated as follows

$$\theta(R+r)=\theta\beta=\frac{360^o}{180^o}\pi\beta \tag{5}$$

$$\theta(R+r)=\theta\beta=2\pi\beta \tag{6}$$

$$\theta(R+r)=\theta\beta=\pi d_\beta \tag{7}$$

$$\dot{\theta}(R+r)=\dot{\theta}\beta=n_{spindle}\pi d_\beta \tag{8}$$

where β is the distance $(R+r)$ and $d_\beta=2\beta$ and $n_{spindle}$ is the number of spindle turn in a minute (rpm). Likewise, the speed of rotation for a traveler can be defined as follows

$$\phi R=\frac{360^o}{180^o}\pi R \tag{9}$$

$$\phi R=2\pi R \tag{10}$$

$$\phi R=\pi d \tag{11}$$

$$\dot{\phi}R=n_{traveler}\pi d \tag{12}$$

Where d is the ring diameter and $n_{traveler}$ is the number of travelers turn in a minute (rpm). Substitute Equation (12) and Equation (8) into Equation (4), then Equation (13 to Equation (15) is obtained below

$$v_f=n_{spindle}\pi d_\beta-n_{traveler}\pi d \tag{13}$$

$$v_f=\left(n_{spindle}\left(\frac{d_\beta}{d}\right)-n_{traveler}\right)\pi d \tag{14}$$

$$v_f=\left(n_{spindle}J_N-n_{traveler}\right)\pi d \tag{15}$$

where $J_N=\left(\frac{d_\beta}{d}\right)$ is a constant value

If we assume that the yarn diameter (2r) is very small compared to ring diameter (2R), therefore $\frac{d_\beta}{d}\approx 1$, hence Equation (15) can be written as shown in Equation (16)

$$v_f=\left(n_{spindle}-n_{traveler}\right)\pi d \tag{16}$$

For a case $d_\beta\approx d$

The twist is defined as the ratio of the spindle rotational speed to the linear velocity of the yarn, v_f, [4], therefore it can be formulated Equation (17) to Equation (24)

$$v_f = \left(n_{spindle} - n_{traveler}\right)\pi d \tag{17}$$

$$\frac{v_f}{\pi d} = \left(n_{spindle} - n_{traveler}\right) \tag{18}$$

$$n_{spindle} = n_{traveler} + \frac{v_f}{\pi d} \tag{19}$$

$$T_{machine} = \frac{n_{spindle}}{v_f} \tag{20}$$

$$T_{machine} = \frac{n_{spindle}}{v_f} = \frac{n_{traveler}}{v_f} + \frac{1}{\pi d} \tag{21}$$

$$T_{machine} = T_{real} + \frac{1}{\pi d} \tag{22}$$

$$T_{machine} - T_{real} = \Delta T \tag{23}$$

$$\frac{\Delta T}{T_{real}} 100\% = \left(\frac{T_{machine} - T_{real}}{T_{real}}\right) 100\% \tag{24}$$

From Equation (23) it can be shown that there is a difference in a twist between a twist set on the machine, $T_{machine}$, and a twist measured using a twist tester, T_{real}, which is equal to ΔT.

Validation of yarn difference Δ*T*

The results of theoretical modeling in Equation (24), which states that there is a high difference between the real yarn twist and the twist on the machine, are then validated experimentally using the Ring spinning machine as well as a twist tester for several different yarn numbers (in unit Ne). The validation of the yarn twist experiment on the machine and the real yarn twist with the twist tester in the evaluation laboratory can be shown in Table 1 below.

Table 1. Experimental difference between yarn twist and machine twist

Yarn count (Ne)	**Real twist using twist tester (TPI)** $\bar{\mathbf{x}}$	**Twist on the machine (TPI)**	ΔT %
20	15,87	17.31	9.073
23	16,84	19.05	13.40
30	21,76	22.41	2.987

RESULTS AND DISCUSSIONS

Based on TABLE 1 and Equations (23) and Equation (24), it was found that there is a match between theory modeling and the results of experimental validation in the field, which states that there is a difference between machine twist and real yarn twist (measured using a twist tester), which is ΔT. In modeling, the theory (Equation (23) and Equation (24)) showed that there would be a large difference in the difference between the yarns in the amount of ΔT, which is influenced by the difference in traveler speed with spindle speed.

Based on theoretical modeling, the linear velocity of drafting must have the form of Equation (16) in the case of the yarn tracing is very small, while in the case of the yarn tracing cannot be ignored, Equation (15) can be used to determine the linear velocity of the drafting. The magnitude of the difference between theoretical modeling is $\frac{\Delta T}{T_{real}}100\% = \left(\frac{T_{machie}-T_{real}}{T_{real}}\right)$. Validation of the ring-spinning machine's experimental discrepancies shows a value of $\frac{\Delta T}{T_{real}}100\%$ of approximately 2.987% to 13.04%. $\frac{\Delta T}{T_{real}}100\% = \left(\frac{T_{machine}-T_{real}}{T_{real}}\right)= 0$. In this particular case, it shows that there is no difference in difference between gaps. In this study, it was also found that there were no discrepancies; it was necessary to require that the spindle rotational speed had the same value as the traveler rotational speed. Based on theoretical modeling results, a large percentage of the twist ratio is influenced by differences in the spindle rotational speed of the traveler rotational speed. Based on kinematics modeling and experimental validation, it is also found that the spindle rotational speed., $n_{spindle}$, will always be greater than the traveler speed of $n_{traveler}$. Based on Equation (22), it was found that the twist on the machine, $T_{machine}$., will have a greater value than the twist on the real yarn, T_{real}. The results of experimental validation in TABLE 1 show that $T_{machine}$ will have a greater twist than T_{real} with a difference of $T_{machine}$-T_{real}= ΔT and the average percentage of approximately 2.987% to 13.04%.

CONCLUSIONS

In this study, the relationship between the number of twists, spindle speed, speed of the traveler, and yarn delivery speed has been formulated. The results of theoretical modeling have been validated experimentally on the ring-spinning machine. Based on the results of this study, both theoretical and experimental validation, the same result is obtained between theoretical modeling and experimental validation, which states that there will be differences in the difference between the twist between the real twist of yarn and the twist on the machine, which is equal to ΔT. The theoretical modeling results state that the difference between these differences arises due to the difference between T_{machine} in which $T_{machine}$ arising from the difference between the speed of n_{spindle} rotational speed and $n_{traveller}$ rotational speed.

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