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Research Article

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Derivation of Yarn Package Radius Measuring System for Yarn Winding Machines

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Abstract

Decreasing waste materials through recycle has in the recent contributed to sustainable manufacturing in many textile industries for better resource utilization in textile mills. This has been given first priority in manufacturing, processing and finishing operations. Most of the time the yarn manufacturing and proper utilization of this material didn't give attention in most companies. Especially yarn length variation of packages, weaving beams and copes have very critical impact on those companies which manufacture and utilize yarn products. This variation problem has great impact on their productivity and profitability. This paper describes the application of a new formula in the yarn packaging process and it is accomplished by derivation a new formula that can determine the radius of any package. The formula has integrated the basic characteristics of yarn and fiber including yarn diameter, yarn/ fiber density and mass of the yarn coiled on the cop. Finally we have concluded that package radius is the quadratic function of yarn density and package mass on the cope.

Keywords: yarn, count, linear density, Package density

[redacted]Introduction

Length determination is an art and science of conveying, elevating, positioning, supplying, packaging and storing of yarn Starting from the time, the raw material. More specifically fibers for spinning unit or yarns for weaving/ knitting unit and fabrics for wet processing or garmenting units enter the mill gate and goes out of the mill gate in the form of finished products [1].

The process needs proper measurement at all stages within the mill boundaries such as within and between raw material stores, various sections of production departments, machine to machine and finished Product stages. The mechanism has great impact on measuring cost and cost of production considerably [2]. Proper Package length measuring adds not only to the cost but also to the product value. The ideal mill would have an absolute minimum of proper measurement and more use of mechanical material measuring device equipment[3].

In yarn spinning department, there are different rooms that involve length of yarn measuring, packaging, intermediate products, wastes, finished goods, stores and maintenance tool equipment's [4]. Throughout fiber to yarn industrial process, raw materials, laps, sliver, roving, yarn, finished goods and wastes) are stored at different places and transported between departments without proper measurement. In spinning mills, the package formation system and automatic length measurement (ribbon lap, roving bobbin, ring bobbin, cone and cope) reduce the measuring activities to a greater extent that significantly contribute to productivity enhancement. The selection of appropriate measuring equipment for performing a particular task is crucial in terms of safety, waste consumption and cost minimization[4, 5].

Productivity is the common aim of all factories in which it is needed to be achieved and being productive is a quality of every factory and a medium of transformation[6, 7]. Better utilization of resources at a right time for a right purpose by a right thing is a means of increasing productivity. But there are barriers which limit the factories from better utilization of resources[8, 9].

In most rewinding machines, there is no proper package length determining mechanism and specification which considers type of count (linear density), package density, yarn diameter, yarn density, package diameter and mass of the package [10]. This causes high length variation between yarn packages. As a result, there is high amount of measuring cost i.e. high amount of resource consumption, fluctuated machine efficiency, winding process difficulties and hence two or more times single stage winding process of identical steps. Since measuring problem is one of the main headache, which leads to decrease both quality and quantity of production. It also takes high amount of labor forces and high loss of time in reprocessing of extra lengths[8].

Now a day's effort in the latest measuring of textiles are directed towards for shortening and simplifying of the measurement process in order to reduce energy consumption, idle time, wastage, and production loss[9, 10]. This research is aimed to formulate new mechanism of package length determining system that relates count of yarn, package density and mass of the yarn which enhance the companies in improving product quality, product quantity, reduce work load of operators and production cost. The information from this paper provides new knowledge into the possible application of package radius measuring formula for use in textile manufacturing.

[redacted]Materials and Methods

2.1. Materials

2.1.1. Yarn

The material was taken from Bahir Dar Textile Share Company, Bahir Dar Ethiopia with 20 Tex counts. The use of linear density (count) to express the yarn fineness provides a convenient and a practical approach for characterizing this important characteristic[9]. All machines in the fiber-to-yarn conversion system are set on the basis of the linear density of fiber strands. In certain applications, however, yarn fineness expressed in diameter or thickness provides more useful information. Perhaps, determining the structural features of a fabric properties corresponding to cover factor and yarn crimp requires a prior knowledge of yarn diameter [9, 11].

2.1.2. Winding cops

The winding cops were selected from the Bahir Dar Textile Share Company with height of cop (17 cm), Radius of wider side (3.4 cm), and radius of the narrow side (1.7 cm).

[redacted]Methods

3.1. Design and Formulation of the new system

3.1.1. Yarn Diameter

From different related works we have found that measuring yarn diameter is important to provide an estimate of its value.[9] [12].

Let us first determine radius of yarn, $\mathrm{R} = \sqrt{\frac{\text{mass per/unit length}}{\pi\rho}}$, ρ = Yarn bulk density [13, 14]. For direct count system (Tex), this general relationship could be as follows. $\text{yarn diameter d} = \mathrm{k1}\sqrt{\frac{\mathrm{tex}}{\rho}}$, k1 = twist factor[15]. On the other hand for indirect systems (cotton count), the general expression of yarn diameter has been described as $\text{yarn diameter d} = \frac{1}{\mathrm{k2}\sqrt{\rho \mathrm{Ne}}}$, where K2 = twist factor [13] [15]

In practice, yarn diameter is typically estimated using empirical formula[8, 16]. One of the most commonly used expressions for estimating yarn diameter is that developed by Peirce in 1937. In this expression, yarn density was assumed to be 1.1 g/cm^3[17]. In a recent study, El Mogahzy et al (1993) developed empirical expressions for estimating the diameters of ring-spun, rotor-spun, and MJS air-jet spun yarns [8, 16] as described in Table **1** below.

Table 1: Empirical Formulas of Yarn Diameter

Yarn Type	Expression	Units	Source
Ring Spun	$d = \frac{1}{28\sqrt{Ne}}$	Inch	[8, 16, 18-20]
Ring Spun	$d = -0.10284 + \frac{1.592}{\sqrt{Ne}}$	Mm	[16, 19, 21-23]
Rotor Spun	$d = -0.16155 + \frac{1.951}{\sqrt{Ne}}$	Mm	[16]
MJS Air-Jet Yarn	$d = -0.09298 + \frac{1.5872}{\sqrt{Ne}}$	Mm	[8, 16]

These expressions (also given in Table above) were developed based on extensive macroscopically testing of actual yarn thickness of the three yarn types using a wide range of yarn count, and twist levels [9, 13, 24].

The main finding of this research was formulation of a new system derived formula by considering different yarn and fiber properties.

Let's start by considering Cone dimension, here the main finding was how to calculate the package radius expressed in cm and this has accomplished with the derivation of diferrent formulations including Volume of frustum of cone formula, yarn density, mass of yarn, length of yarn, quadratic formula and other parameters.

3.2. **Volume of frustum of cone**

Consider the standard Cone dimension: h=170mm and D=68mm, d=34mm.

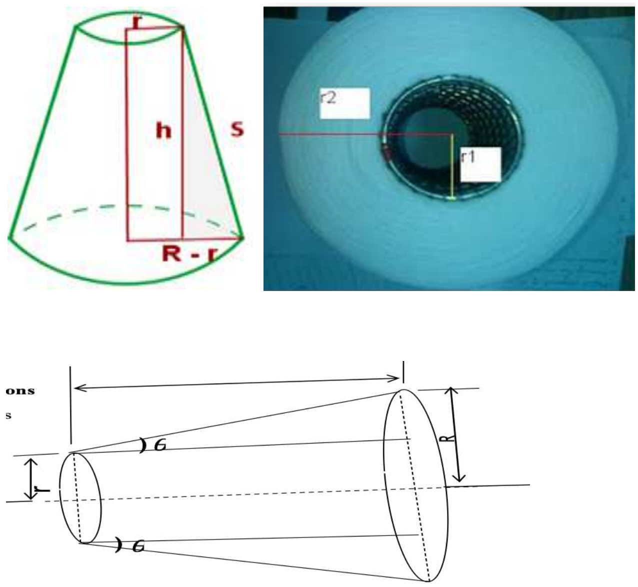

Figure 1: standard Cone dimensions

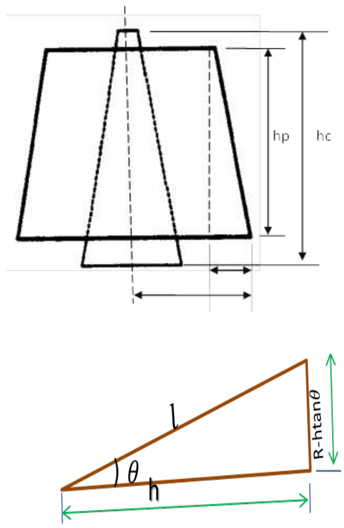

Figure 2: package parameters

$\mathrm{Vc} = \frac{1}{3}\pi h_c({R_c}^2 + {r_c}^2 + R_c \times r_c \dots\dots\dots\dots$ (Equation 1) [13, 25]

where, $R_c = \text{larger radius of the cope}, r_c = \text{smaller radius of the cope},$

$$h_c = \text{height of the truncated cope}, \pi = 3.14$$

Now the new formulation of the package measurement system and calculations were described below.

Volume of a full Package could be described as

$V_p = \frac{1}{3}\pi h_p({R_p}^2 + r^2 + R_p \times r_p \;\dots\dots\dots\dots\dots.$ (Equation 2)

Where, $R_p = \text{larger radius of the packagee}, r_p = \text{smaller radius of the package}, \; h_p = \text{height of the package of wrapped yarn}.$

Then Volume of yarn

$V = V_p - V_c \;\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$ (Equation 3)

$V_y = \frac{M_y}{D_y} = \frac{M_p}{D_p} \dots\dots\dots..\dots\dots\dots\dots\dots\dots\dots..\dots.$ (Equation 4)

Where, Vp =volume of the package, Vy = volume of yarn, Vc=volume of the cone, My = mass of the yarn, Mp=mass of package, Dp=density of yarn=density of package[26, 27].

$\tan\theta = \frac{R-r}{h}$ … … … … … … … … … … … . (Equation 5)

(From phytogorous theorem)[28, 29]

$$h\tan\theta = R - r \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \text{(from Equation 5)}$$

$r = R - h\tan\theta$, from (Equation 1) and (Equation 5)

We have the relation, $v = \frac{\pi h}{3}(R^2 + R(R - h\tan\theta) + (R - h\tan\theta)^2)$ [13, 24, 25]

Quadratic function for relating other parameters

now this equation gives a certain quadratic equation with

$F(x) = a\,x^2 + bx + c = 0$ [15], $a = 3, b = 3h\tan\theta,\ c = (h\tan\theta)^2 - \frac{3Mp}{\pi hDp}$, X=Rp

$$\text{then the radius of the package } R_p = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$Rp = \frac{-3h\tan\theta \pm \sqrt{(3h\tan\theta)^2 - 4 * 3((h\tan\theta)^2 - \frac{3Mp}{\pi hDp})}}{2 * 3} \quad [15]$$

Now from equation 3, we have, $V_y = V_p - V_c$

Relating volume of full package and empty cone

$$\text{volume of the cone can be calculated as } V_c = \frac{1}{3}\pi h_c\left({R_c}^2 + {r_c}^2 + R_c \times r_c\right)$$

$$h_c = 17\text{cm}, \qquad R_c = 3.4\text{cm},\ r_c = 1.7\text{cm}$$

$$\text{then } V_c = \frac{1}{3} 3.14 * 17_{cm} * ((3.4_{cm})^2 + (1.7_{cm})^2 + 3.4_{cm} \times 1.7_{cm}) = 359.96\text{cm}^3$$

3.3. Mass of yarn on the package

Now to calculate mass of the yarn we can use either the length of the yarn we are intended to prepare or direct measuring of the full package with torsion balance and subtract the mass of the empty cone. For example let`s determine the length of the yarn ``L`` and calculate mass of the yarn from the yarn linear density[9].

$M\,(g) = L(m) * \frac{0.5905}{\text{yarn count(Ne)}}$ … … … ..(Equation 6) [9, 30]

It can be also determined from the data of cotton yarn density [31]

$$D\left(\frac{g}{cm^3}\right) = \frac{4}{d^2 * \pi} * \frac{m}{l} = \frac{4}{d^2 * \pi} * \text{Tex} * 10^{-5}$$

$V_p = \frac{1}{3}\pi h_p({R_p}^2 + r^2 + R_p \times r_p$ … … … … … . (From Equation 2)

$V_y = \frac{M_y}{D_y} = V_y = \frac{M_y}{D_p}$ … … … . . … … … … … … . . … . (from Equation 3)

Then by back substitution we can calculate the radius of the package

$$R_p = \frac{-3\mathrm{h}\tan\theta \pm \sqrt{(3\mathrm{h}\tan\theta)^2 - 4 * 3((\mathrm{h}\tan\theta)^2 - \frac{3\mathrm{Mp}}{\pi \mathrm{hDp}})}}{2 * 3}$$

This is the final formula derived for determining the radius of any package of yarn with any type of count to set the required yarn length on any package. This reveals that package radius is the quadratic function of yarn density and mass of yarn on the package.

[redacted] Results

As stated previously this will be a very real way of overwhelming the wastages of the mechanical method of altering the winding parameters. The most interesting development here is that, the system can be operated on every type of count as well as the variety of yarn length in a uniform system of any winding principle. The radius of the package can be calculated with the help of excel sheet simply by inserting the required parameters Table **2**.

Table 2: measured radius of the packages

Length (m)	**63000**	**64000**	**66000**	**67000**	**88000**
Count (Ne)	Radius (cm)				
14	6.463947	6.522803	6.639127	6.696617	7.816245
16	5.982765	6.03789	6.146837	6.200679	7.2491
20	5.245628	5.29506	5.392749	5.441025	6.380744
21	5.094867	5.143138	5.238533	5.285675	6.203233
30	4.094695	4.135318	4.215586	4.255248	5.02662
32	3.931388	3.970773	4.048591	4.087041	4.83472

When we see the radius of each length of yarn package with various yarn count, the results showed that as the yarn count increase, the radius of the package decrease for a constant yarn length; but as the length increase, the radius of the package increase for a constant yarn count as shown in Figure **3** below.

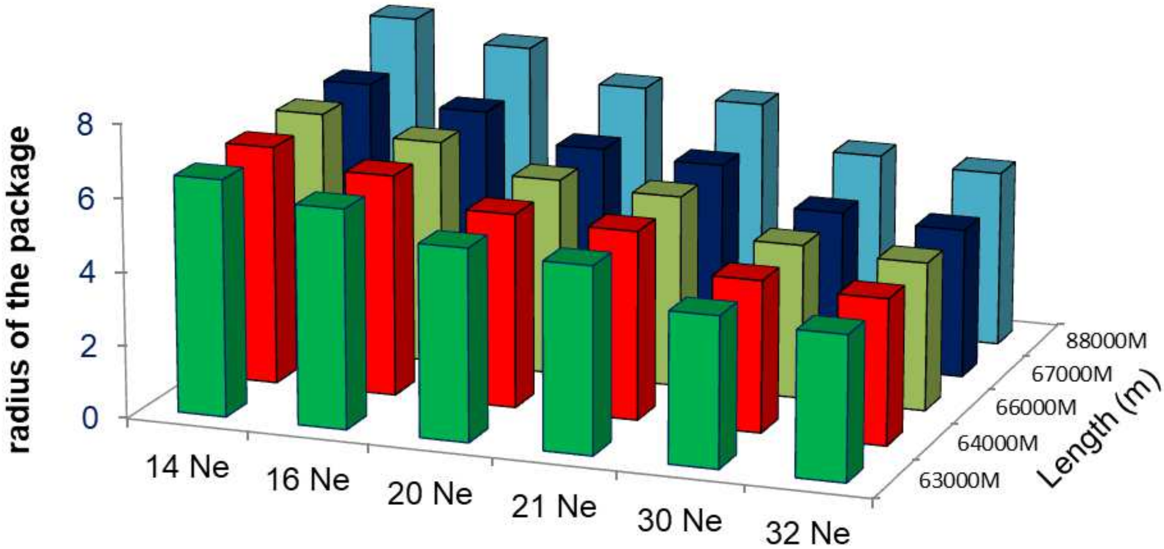

Figure 3: graphical representation of radii of the yarn packages with different count and yarn length

[redacted] CONCLUSION

In this research work, the implementation of package length determination formulae has been proposed as a solution for the current problems in the spinning mill companies. The length determination mechanism comprises strongly interrelated characteristics of the yarn and the produced packages. Those components address the areas relevant to package uniformity in manufacturing process.

The goal of the formulation was to reduce high wastage of yarns due to yarn length variation of packages in spinning and winding mill industries. It has high advantages to spinning companies in different aspects including production rate, quality of products, decrease operators' workload, and reduce the amount of yarn wastes and other resources.

The research has already accomplished by designing a new integrated yarn package length measuring system for the production of uniform packages without length variation for winding and rewinding machines. Generally the study can reduce cost of production by 15.01% in Bahir Dar Textile Share Company.

[redacted]Declarations

1. Funding

- 'Not applicable'

2. Code availability

- 'Not applicable'

3. Ethics approval

- 'Not applicable'

4. Consent to participate

- 'Not applicable'

5. Consent for publication

- 'Not applicable'

6. Data Availability

The data used to support the findings of this study are included within the article.

7. Conflicts of Interest

The authors declare that they have no conflicts of interest.

8. Acknowledgments

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