EFFECT OF TECHNOLOGICAL WINDING PARAMETERS ON YARN PACKAGE DENSITY

Tran Duc Trung[1], Dao Anh Tuan[1], Chu Dieu Huong[1,*]

DOI: http://doi.org/10.57001/huih5804.2024.171

ABSTRACT

This paper presents the experimental results on the simultaneous influence of four technological parameters during winding process: the winding speed (Z_1), the load on the friction discs of the yarn tensioner (Z_2), the distance between the bobbin and the yarn guide (Z_3) and the pressure of package on the grooved drum (Z_4) on the winding density of conical yarn package. By using the orthogonal experimental, with the help of the software Excel 2019 and Design Expert 11, the mathematical models describing the relationships between four technological parameters and the winding density of the yarn packages were establised when the winding three ring yarn types: carded Ne 31/1 CVCD, combed Ne 30/1 CVCM, combed Ne 30/1 COCM. The research result is the scientific basis for selecting the optimal technological parameters to achieve the winding density when winding of three types of yarn respectively: 0.534g/cm^3, 0.519g/cm^3, 0.501g/cm^3 on request or predict the winding density before winding with the option of choosing the defined technological parameters.

Keywords: *Package Hardness; Technological parameters; Winding; Yarn package density.*

[1]Hanoi University of Science and Technology, Vietnam
[*]Email: huong.chudieu@hust.edu.vn
Received: 10/8/2023
Revised: 15/10/2023
Accepted: 25/5/2024

1. INTRODUCTION

Winding is the most important stage of the weaving preparation. The product of this stage is the yarn packages. Package quality affects product quality and the productivity of all machines after winding such as warping, weft winding, shuttleless weaving, knitting and dying.

Package quality [1, 2] is evaluated by the yarn quality parameters on the package: yarn count, strength, elongation, unevenness, hairiness, imperfactions (IPI), splice strength, foreign fibers in yarn, seldom faults (if required), and wound package quality (winding density and yarn package hardness, evenness of yarn length, patterning on the wound packages and other visual defects of the packages). If the winding density is too low, package will be soften and deform during transportation, storage and use, difficult to find yarn ends to joint when breaking yarns because these ends were adherent on the surface of the packages. If the winding density is too high, breakage rate of yarn when winding increases due to high yarn tension, yarn will have many joints, winding productivity will also decrease and the dyes are difficult to penetrate into the yarn layers, the yarn layers will be uneven in color. Due to the specificity of each stage after winding, the winding density for each stage will be different. In the case that after winding is the dyeing stage, the winding density is 0.28 ÷ 0.4g/cm^3 (for cotton yarn), and the winding density from 0.4 to 0.6g/cm^3 is suitable for warping, weft winder, knitting, shuttleless machines for the yarn to be easily removed from the package [3].

Scientific studies have shown that, there are many factors that affect the winding density. The winding density varies according to the package diameter and the crossing angle 2β of the turns on the package [4], when the crossing angle 2β is zero, the package will have the highest winding density (in the case of a parallel wound package), and when 2β is 90^0, the package will have the smallest winding density [3]. Winding density increases with yarn tension. When winding 100% cotton yarn 30tex, winding speed 10m/s, if yarn tension increases by 0.01N, winding density will increase by 0.005g/cm^3 [5]. Winding density also depends on the pressure P of the package on the grooved drum. When winding 100% cotton yarn 30tex, the winding speed of 800m/min shows that the larger the pressure P, the higher the winding density, if P increases by 1N, the winding density will increase by 0.004g/cm^3 [3]. According to Gugor Durur [6], in winding100% cotton yarn with the speed of 450m/min, if the pressure of the package on the grooved drum is 20N, the yarn tension increases from 8 ÷ 30cN, the winding density increased from 0.381g/cm^3 ÷ 0.478g/cm^3. According to this study, when it is necessary to wind a package with the specified winding density, if the yarn tension is increased, the pressure of the package on the grooved drum must be reduced. Research [7] also shows that, yarn tension increases, thus increasing package hardness, the relationship between winding density and package hardness is linear. Research results [8, 9] have established the linear relationship between package hardness and some parameters related to yarn tension.

According to the research of Duc Duong Pham, Van Chat Nguyen [10]: The higher the yarn tension when winding, the higher the package density and the hardness (Shore) of the package and higher the color difference between the layers of yarn in a package. M. B. Nazarova [11] has also determined the mathematical relationship between three parameters: winding speed, the load on the friction discs of the yarn tensioner and the height of the baloon to the package density for three types of yarn: cotton, polyester and PES/CO blends. The effect the pressure of package on the grooved drum on the winding density has not been mentioned yet.

Winding the package with the required winding density or predicting the winding density before winding is a work of scientific and practical significance. However, to achieve this goal, it is not possible to study the simultaneous influence of all factors on the winding density, but to select typical factors to study the influence on the winding density,research results have practical significance. This paper presents the experimental results on influence of four technological parameters during the winding process: the winding speed (Z_1), the load on the friction discs of the yarn tensioner (Z_2), the distance between the bobbin and the yarn guide (Z_3) and the pressure of package on the grooved drum (Z_4) on the average winding density.

2. EXPERIMENTAL

2.1. Materials

Three types of yarn are wound on the same kind of bobbin producted by Vinatex NamDinh (Vietnam) spinning mill (Table 1).

Table 1. The parameters of three types of yarns

Parameters	Yarn CVCD	Yarn CVCM	Yarn COCM
Type of yarn	Carded (60% cotton, 40% polyester)	Combed (60% cotton, 40% polyester)	Combed (100% Cotton)
Yarn count (hank/pound)	31/1	30/1	30/1
Yarn twist (t/m)	760	744	766
Breaking Force (cN)	284.7	289.7	277.8
Elongation (%)	6.2	6.25	4.44
Tenacity (cN/tex)	15.04	14.91	14.34
Hairiness	5.61	5.55	5.7
Unevenness U (%)	11.01	9.44	8.94

2.2. The winding model

Winding is performed on the developed model in the Hanoi University of Science and Technology [12]. The principle diagram of the winding model is shown in Fig. 1.

Yarn 10 is removed from the bobbin 9, through the yarn guide 11, yarn tensioner 12, yarn clearer 13, yarn guide 14, grooved drum 7 and then wound on the package 8. Short branch of the package holder 1 connected to piston rod 2 moving in cylinder containing air (oil) 4. One end of lever 5 rests on stop plate 3 fastened on piston rod, the other end of this lever is connected to spring 6. When the diameter (mass) of the package 8 increases, lever 5 rotates counter-clockwise, force D at B_1 remains constant because moment M considering O1 remains constant:

$$M = D.B_1O_1 = S.y = \text{constant} \quad (1)$$

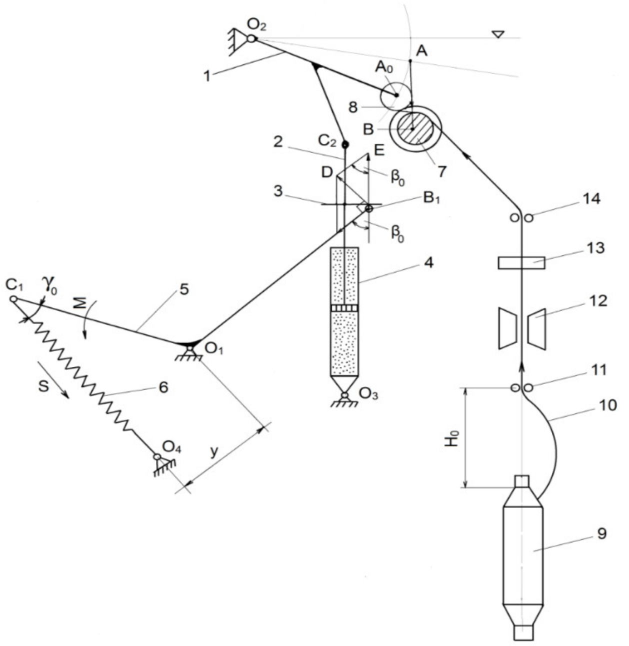


Fig. 1. Principle diagram of the winding model

The moment M remains constant because the pulling force S of spring 6 decreases, but the distance y from the spring to O_1 increases to compensate. As a result, the angle β^0 decreases, the force E at B_1 increases according to equation (2) and keeps the pressure of the package on the grooved drum constant during winding.

$$E = \frac{D}{\sin\beta_0} \quad (2)$$

The pressure parameter of the package on the grooved drum before winding is adjusted through the pulling force of spring 6 and a suitable load is applied to the package holder. Adjusting the rotation speed of the drive motor to the grooved drum shaft through the frequency converter will achieve the required winding speed. The established winding model is considered to be an analogous physical model that allows to change the winding parameters for research purposes. Experimental research on the winding model is low cost, short research time and does not affect production.

2.3. Determination of winding density

The winding density of yarn package y is determined by the formula [13]:

$$y = \frac{G}{V}\ (\text{g/cm}^3) \quad (3)$$

Where:

G: Weight of the yarn wound on the package (g), determined by electronic scale FY2000B, accuracy 0.1g.

V: Volume of the package (cm^3) is calculated:

$$V = \frac{\pi}{4}(D_{tb}^2 - d_{tb}^2).L_{tb} \quad (4)$$

$$D_{tb} = \frac{D_1 + D_2}{2}; \quad d_{tb} = \frac{d_1 + d_2}{2}; \quad L_{tb} = \frac{L_1 + L_2}{2}$$

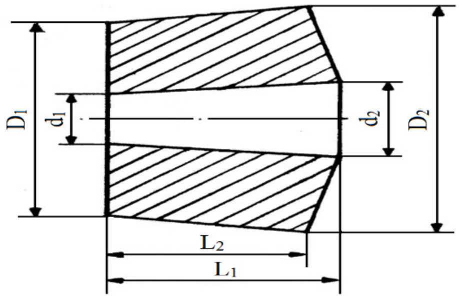


Fig. 2. Cone package

Dimentions of the package are measured by Kasupi (Japan) electronic caliper, measuring range 0 ÷ 150mm, resolution 0.01mm, measuring speed 3m/s, working temperature from 0 ÷ 40^{0}C, relative humidity below 80%.

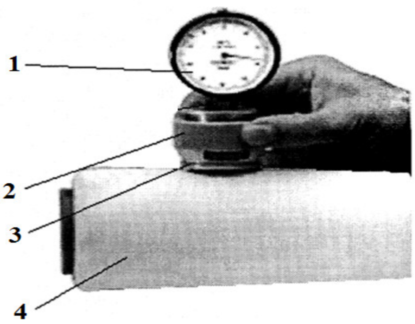


Fig. 3. Yarn Package Hardness Tester HP - 5

1. Display range; 2. Knurled shell; 3. Red marking; 4. Package

Fig. 3 shows the cone package - a product of the winding process. In order to determine the winding density Y of the package, the mass G and volume V of the yarn wound on the package must be determined. The package hardness was measured by the Yarn Package Hardness Tester HP-5 310-06248 [14] of Hans Schmidt (Germany) with the ball diameter 5mm, depth of indentation: 0 ÷ 2.5mm, display range: 0 ÷ 100 hardness graduation marks, test pressure: Approx. 12.5N, measuring spring force: 0.55 ÷ 8.065N, accuracy ± 0.1 Shore. Scope of application: measure the hardness of the package (bobbin) of yarns. The Yarn Package Hardness Tester also has the following features: The spring loaded outer ring assures a constant measuring pressure and eliminates false readings due to difference between operators, ball shaped indentor prevents damage to packages, working face slightly curved to fit on small packages, working surface radius is 55mm.

2.4. Using second-level orthogonal experimental planning [15] to creat the experimental matrix and determine the regression functions with the help of Excel 2019 and Design Expert 11 software.

3. RESULTS AND DISCUSSION

3.1. Determination of influence of technological paramaters on the winding density

3.1.1. Determination of the range of variation of technological parameters

The variation range of the technological parameters: the winding speed (Z_1), the load on the friction discs of the yarn tensioner (Z_2), the distance between the bobbin and the yarn guide (Z_3) and the pressure of package on the grooved drum (Z_4) in Table 2 is determined on the basis of inheriting the studies on the influence of some technological factors on the winding density, surveying the winding conditions of common yarns in the factories, the quality of yarn before winding and the allowable capacity of the fabricated winding model.

Table 2. Center value and range of technological parameters

Parameters	Actual values				Coded values			
	Z_1 (m/min)	Z_2 (cN)	Z_3 (cm)	Z_4 (N)	X_1	X_2	X_3	X_4
Top level	1200	30	18	21	+1	+1	+1	+1
Base lavel Z_j^0	900	20	14	14	0	0	0	0
Bottom level	600	10	10	7	-1	-1	-1	-1
Variation range ΔZ_j	300	10	4	7	-	-	-	-

3.1.2. Experimental coding and matrixing

The empirical regression function for coding variables has the following general form:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2$$

To creat the empirical matrix, first convert Z_j to x_j according to the formula:

$$x_j = \frac{Z_j - Z_j^0}{\Delta Z_j} \quad (5)$$

Then, make a full experimental table. The number of experiments N with the number of variables k = 4 is determined by the $N = 2^k + n_0 + 2k$ where, n_0 is the number of experiments in the center ($n_0 = 1$). So, N = 25. Coefficient $\alpha = \sqrt{\sqrt{N.2^{k-2}} - 2^{k-1}} = \sqrt{\sqrt{25.2^2} - 2^3} = 1.414$.

Experimental matrix and experimental results are shown in Table 3 in which, y_1, y_2, y_3 are the average winding density of the packages, determined when winding the packages to four different diameters according to each test plan with 3 yarn types Ne 31/1 CVCD, Ne 30/1 CVCM and Ne 30/1 COCM.

Table 3. Experimental matrix and experimental results (k = 4; n_0 = 1)

N^0	x_0	x_1	x_2	x_3	x_4	Z_1	Z_2	Z_3	Z_4	y_1	y_2	y_3
1	+	-	-	-	-	600	10	10	7	0.381	0.410	0.367
2	+	+	-	-	-	1200	10	10	7	0.575	0.581	0.507
3	+	-	+	-	-	600	30	10	7	0.494	0.499	0.467

4	+	+	+	-	-	1200	30	10	7	0.6	0.597	0.521
5	+	-	-	+	-	600	10	18	7	0.466	0.478	0.44
6	+	+	-	+	-	1200	10	18	7	0.535	0.558	0.496
7	+	-	+	+	-	600	30	18	7	0.526	0.539	0.49
8	+	+	+	+	-	1200	30	18	7	0.612	0.618	0.532
9	+	-	-	-	+	600	10	10	21	0.482	0.480	0.455
10	+	+	-	-	+	1200	10	10	21	0.668	0.663	0.570
11	+	-	+	-	+	600	30	10	21	0.523	0.524	0.474
12	+	+	+	-	+	1200	30	10	21	0.608	0.615	0.528
13	+	-	-	+	+	600	10	18	21	0.505	0.520	0.471
14	+	+	-	+	+	1200	10	18	21	0.545	0.571	0.502
15	+	-	+	+	+	600	30	18	21	0.548	0.573	0.504
16	+	+	+	+	+	1200	30	18	21	0.638	0.632	0.544
17	+	0	0	0	0	900	20	14	14	0.611	0.616	0.530
18	+	α	0	0	0	1324	20	14	14	0.642	0.634	0.565
19	+	-α	0	0	0	475	20	14	14	0.513	0.522	0.473
20	+	0	α	0	0	900	34.14	14	14	0.58	0.582	0.508
21	+	0	-α	0	0	900	5.86	14	14	0.503	0.515	0.468
22	+	0	0	α	0	900	20	19.65	14	0.595	0.588	0.510
23	+	0	0	-α	0	900	20	8.34	14	0.531	0.554	0.492
24	+	0	0	0	α	900	20	14	23.9	0.559	0.56	0.497
25	+	0	0	0	-α	900	20	14	4.1	0.518	0.574	0.506

3.1.3. Establishing the regression equations

By using the Design Expert software, the regression coefficients have been calculated and tested according to Student's standards. After removing the insignificant coefficients, we get the regression equations of the following forms:

$$Y_1 = 0.5503 + 0.0519x_1 + 0.025x_2 + 0.0193x_4 - 0.0179x_1x_3 - 0.0168x_2^2 - 0.0183x_4^2$$

$R^2 = 0.924$

$$Y_2 = 0.5601 + 0.0485x_1 + 0.0215x_2 + 0.0084x_3 + 0.0139x_4 - 0.0099x_1x_2 - 0.0171x_1x_3 + 0.0084x_2x_3 - 0.0188x_2^2$$

$R^2 = 0.937$

$$Y_3 = 0.4967 + 0.0331x_1 + 0.0154x_2 + 0.0058x_3 + 0.0108x_4 - 0.0095x_1x_2 - 0.0121x_1x_3 - 0.0093x_2x_4 - 0.0064x_3x_4 - 0.0142x_2^2$$

$R^2 = 0.918$

3.1.4. Checking the suitability of the regression equations with the experiment

The redundant variance is determined as follows:

$$S_{du}^2 = \frac{\sum_{i=1}^{N}\left(y_i - Y_i\right)^2}{N-m} \quad (6)$$

Where:

N: the number of experiments (N = 25)

m: the number of signficant coefficients of the regression equation

y_i: the mean output parameter in *i*-th experiment

Y_i: the analytically predicted output parameter in that experiment

The adequacy of the mathematical model is verifed on the basis of the Fisher test:

$$F = \frac{S_{du}^2}{S_{th}^2} \quad (7)$$

Fisher F_p standard is seen in the table for signficance level p = 0.05, degrees of freedom of redundant variance $f_1 = N - m$, degrees of freedom of regenerative variance S_{th}^2: $f_2 = n_0^{'} - 1 = 3$. (additional experiments at the center, n' = 4). $F_{0.05}(f_1, f_2) = F_p$.

If $F < F_p$ => Suitable model

- For the regression equation Y_1:

$$F = \frac{S_{du}^2}{S_{th}^2} = \frac{0.00193838}{0.0004} = 4.8 < F_p = F_{0.05}(18, 3) = 8.65$$

- For the regression equation Y_2:

$$F = \frac{S_{du}^2}{S_{th}^2} = \frac{0.0008982}{0.00016} = 5.72 < F_p = F_{0.05}(16, 3) = 8.69$$

- For the regression equation Y_3:

$$F = \frac{S_{du}^2}{S_{th}^2} = \frac{0.0005448}{0.00011} = 5.05 < F_p = F_{0.05}(15, 3) = 8.703$$

The established regression equations Y_1, Y_2, Y_3 are suitable with the experiment.

The regression coefficients represent the influential level of the technological parameters on the winding density. From the obtained results we see:

- In the selected range, 4 technological parameters are winding speed (x_1), the load on the friction discs of the yarn tensioner (x_2), distance between the bobbin and the yarn guide (x_3) and the pressure of the package on the grooved drum (x_4) all have influence on the winding density of the package.

- Of the four technological parameters selected, the winding speed (x_1) has the greatest influence on the winding density (the coefficients b_1 in the regression equations Y_1, Y_2, Y_3 are all maximal values and equal to: 0.0519; 0.0485; 0.0331), follow by the effect of the load on the friction discs of the yarn tensioner (x_2) on the winding density (coefficient b_2 has values 0.025; 0.0215; 0.0154 in the equations Y_1, Y_2, Y_3).

In order to see the influence of two parameters (x_1) and (x_2) on the winding density Y, the regression equations are analyzed and calculated in two cases:

1. The winding speed x_1 (Z_1) changes at levels: -1 (600m/min); 0 (900m/min); 1 (1200m/min). The remaining

parameters: x_2 (Z_2); x_3 (Z_3); x_4 (Z_4) are fixed at encoding level 0 at the center.

2. The load on the friction discs of the yarn tensioner x_2 (Z_2) changes at levels: -1 (10cN); 0 (20cN); 1 (30cN). The remaining parameters: x_1 (Z_1); x_3 (Z_3), x_4 (Z_4) are fixed at encoding leval 0 at the center.

Calculated results are presented in Tables 4, 5 and Figs. 4, 5.

Table 4. The calculated results of the winding density Y (g/cm^3) when the winding speed x_1 (Z_1) changes

Loại sợi	Parameter	The values of parameters		
	x_1	-1 (600m/min)	0 (900m/min)	1 (1200m/min)
Ne 31/1 CVCD	Y_1	0.498	0.550	0.602
Ne 30/1 CVCM	Y_2	0.512	0.560	0.609
Ne 30/1 COCM	Y_3	0.464	0.497	0.529

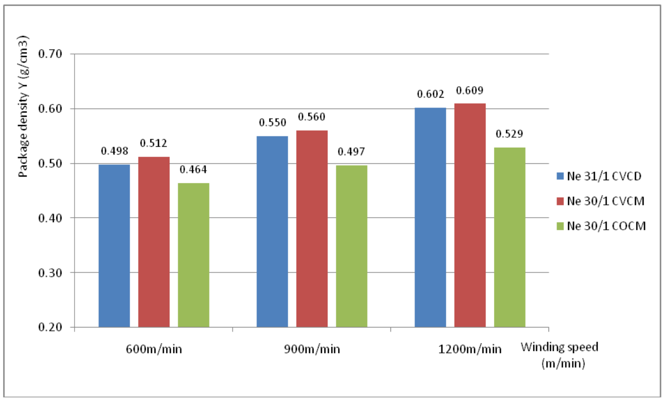


Fig. 4. Effect of winding speed on package density

Table 5. The calculated results of the winding density Y (g/cm^3) when the load x_2 (Z_2) changes

Yarn	Parameter	The values of parameters		
	x_2	-1 (10cN)	0 (20cN)	1 (30cN)
Ne 31/1 CVCD	Y_1	0.525	0.550	0.575
Ne 30/1 CVCM	Y_2	0.539	0.560	0.582
Ne 30/1 COCM	Y_3	0.481	0.497	0.512

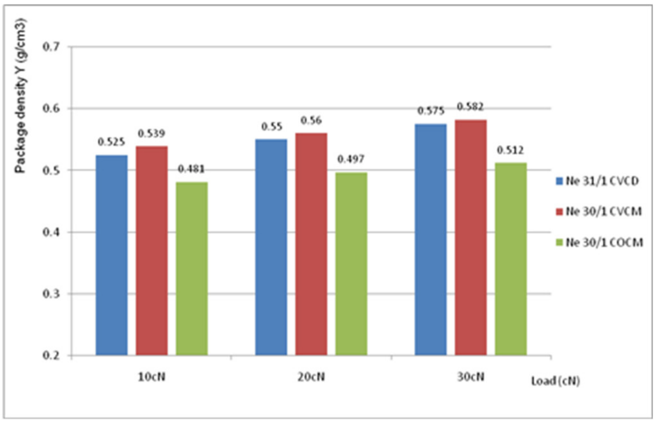


Fig. 5. Effect of the load on the friction discs of the yarn tensioner on package density

It can be seen:

- When winding the 3 types of yarn mentioned above, the winding density increases with the winding speed x_1 (Z_1) and the load on the friction discs of the yarn tensioner x_2 (Z_2).

- Winding speed Z_1 increased by 100% (from 600 to 1200m/min), winding density Y_1 increased by 20.88% (from 0.498 to 0.602g/cm^3); Y_2 increased by 18.94% (from 0.512 to 0.609g/cm^3); Y_3 increased 14% (from 0.464 to 0.529g/cm^3). The load Z_2 increased by 200% (from 10 to 30cN). Y_1 increased by 9.52% (from 0.525 to 0.575g/cm^3); Y_2 increased by 7.98% (from 0.539 to 0.582g/cm^3); Y_3 increased by 6.44% (from 0.481 to 0.512g/cm^3).

- The increase of the winding density when the winding speed increases by 100% is higher than the increase of the winding density when the load on the friction discs of the yarn tensioner increases by 200%, proving that the influence of the winding speed is larger than the effect of the load to the winding density.

- The interaction between these 4 technological parameters is also shown quite clearly through the coefficients (coefficients b_{13} in equation Y_1, coefficients b_{12}, b_{13}, b_{23} in equation Y_2 and coefficients b_{12}, b_{13}, b_{24}, b_{34} in equation Y_3). In case the coefficients are negative, that is the variation of the winding density and the pairs of technological parameters is inverse and vice versa. When at the same time or one of these 4 technological parameters changes, the winding density will change accordingly.

- It is possible to see the image of the surfaces representing the relationship between the pairs of parameters of the objective function on the basis of fixing the remaining parameters at the encoding level 0 at the center through the 3D graph. Figs. 6, 7 (Ne 31/1 CVCD); Figs. 8, 9 (Ne 30/1 CVCM); Figs. 10, 11 (Ne 30/1 COCM).

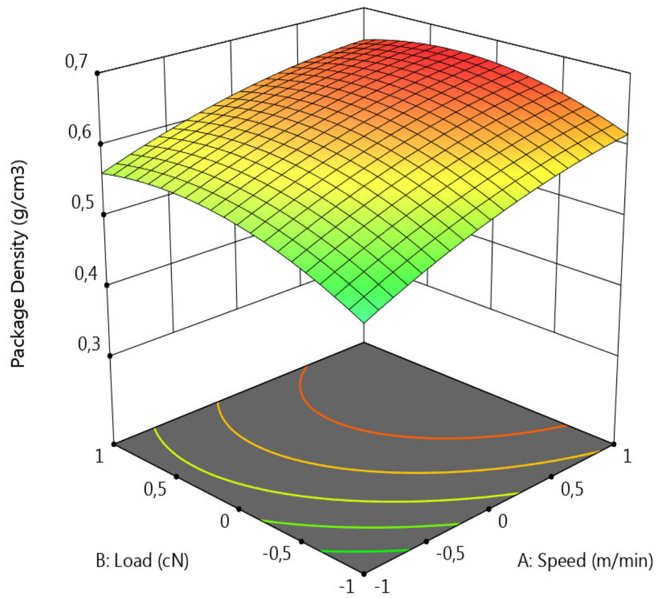


Fig. 6. The surface shows the variation of the winding density depending on the winding speed and the load on the friction discs of the tensioner

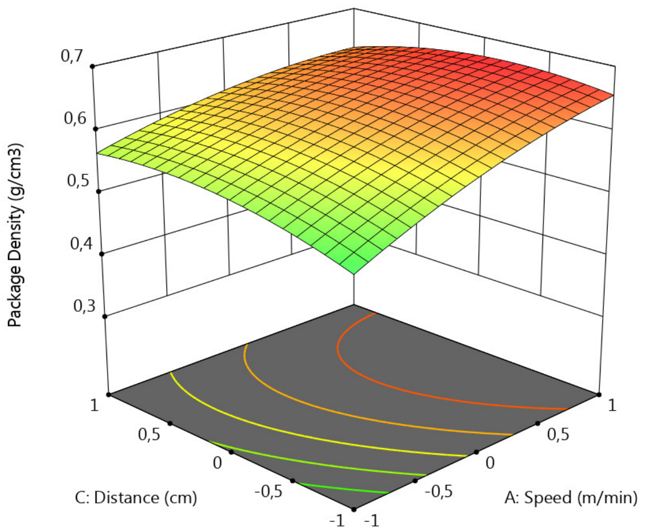


Fig. 7. The surface shows the variation of the winding density depending on the winding speed and the distance between the bobbin and the yarn guide

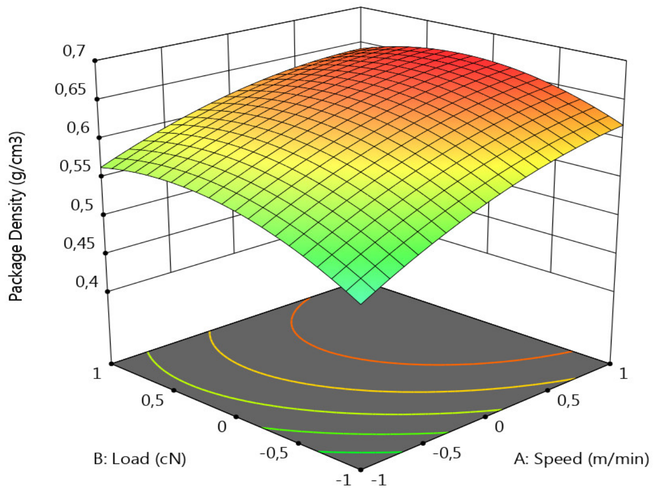


Fig. 8. The surface shows the variation of the winding density depending on the winding speed and the load on the friction discs of the tensioner

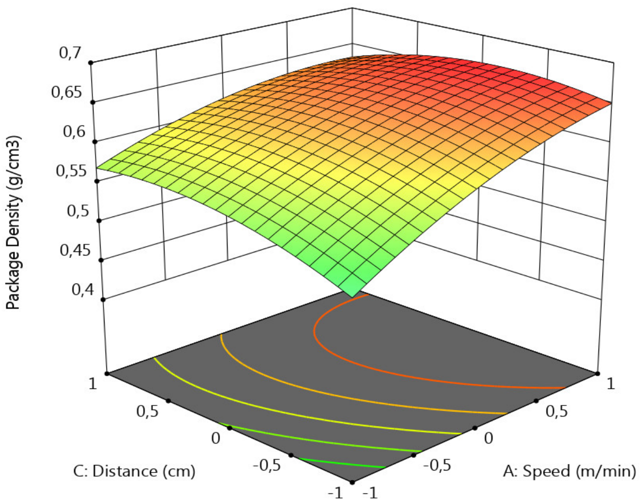


Fig. 9. The surface shows the variation of the winding density depending on the winding speed and the distance between the bobbin and the yarn guide

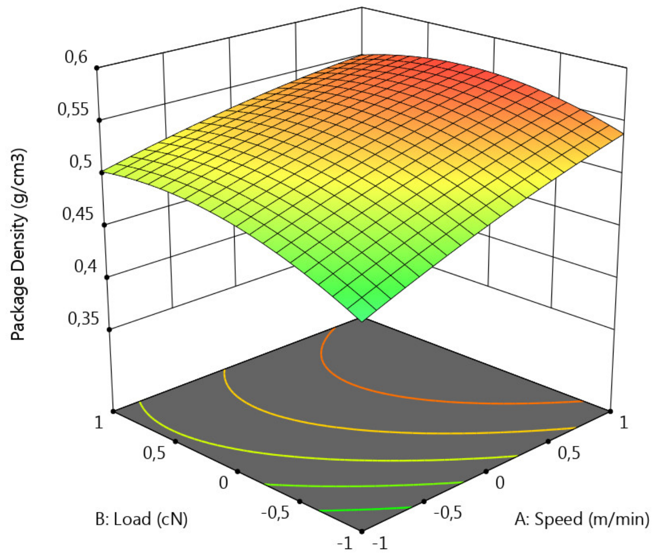


Fig. 10. The surface shows the variation of the winding density depending on the winding speed and the load on the friction discs of the tensioner

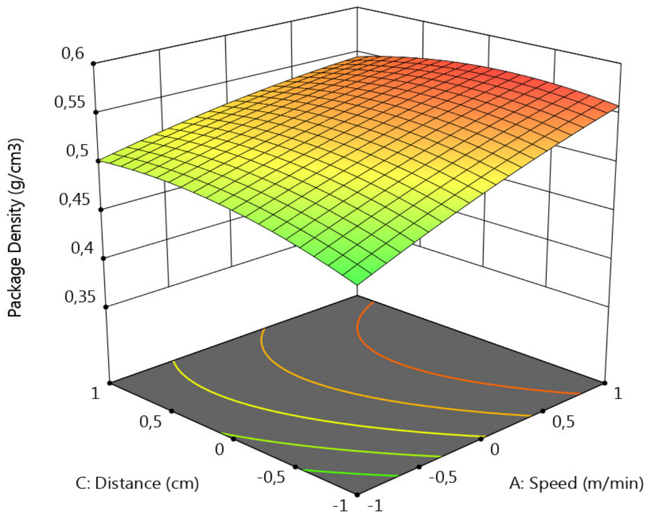


Fig. 11. The surface shows the variation of the winding density depending on the winding speed and the distance between the bobbin and the yarn guide

3.1.5. Determiniation of optimal technological parameters

The optimal technological parameters are determined from the point of view of achieving the required winding density and high winding speed as possible within the range of the study. However, with high winding speed, the quality of the yarn after winding will be greatly reduced, especially the hairiness of the yarn after winding will increase significantly, the yarn breakage will increase, and the efficiency of the winding machine will decrease. With the 3 types of yarn in this study, winding with a maximal speed not exceeding 1000m/min (0.333) is reasonable. The results of the determinaton of the optimal technological parameters to achieve the required winding density Y (Table 6) in accordance with the technological requirements of the following stages of winding: warping, shuttle weaving and knitting... as mentioned in the problem statement.

Table 6. The results of determinaton of the optimal technological parameters

Yarn	x_1	x_2	x_3	x_4	Z_1 (m/ph)	Z_2 (cN)	Z_3 (cm)	Z_4 (N)	Y (g/cm³)	Y_k (g/cm³)
Ne 31/1 CVCD	0.333	0.5445	1	- 0.9757	1000	25.4	18	7.2	0.534	0.562
Ne 30/1 CVCM	0.333	- 1	1	- 1	1000	10	18	7	0.519	0.542
Ne 30/1 COCM	0.333	0.1034	-0.5707	- 0.5059	1000	21.1	11.7	10.5	0.501	0.529

Table 7. The values of the average diameter D_{tb}, winding density Y and hardness C of the package

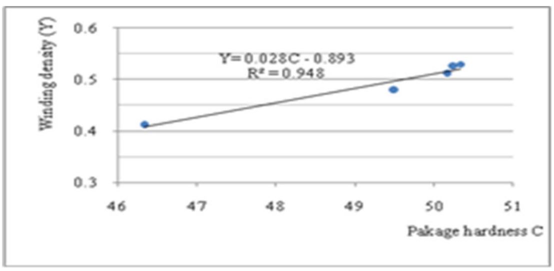
Times of measure-ment	Yarn Ne 31/1CVCD			YarnNe 30/1CVCM			Yarn Ne 30/1COCD		
	D_{tb} (mm)	Winding density Y (g/cm³)	Hardness C (Shore)	D_{tb} (mm)	Winding density Y (g/cm³)	Hardness C (Shore)	D_{tb} (mm)	Winding density Y (g/cm³)	Hardness C (Shore)
1	68.84	0.411	46.33	68.45	0.446	48.58	67.83	0.436	46.42
2	78.72	0.479	49.50	78.52	0.478	49.33	78.99	0.47	47.17
3	87.25	0.511	50.17	87.63	0.498	49.50	88.04	0.49	47.83
4	95.41	0.525	50.25	95.84	0.523	49.75	95.29	0.52	49.67
5	103.54	0.53	50.33	100.53	0.571	51.83	102.52	0.532	51.33

In which, $Z_j = x_j.\Delta Z_j + Z_j^0$. The experimental results verified with the optimal technological parameters determined that the winding density Y_k was only less than 6% different from the calculated winding density.

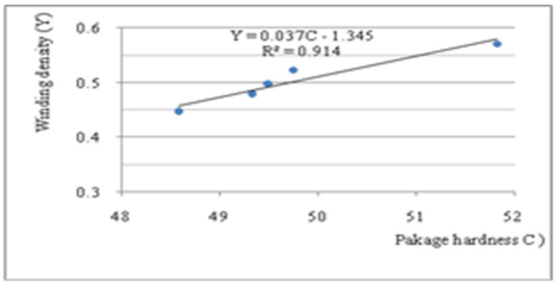
3.2. Determination of the relationship between winding density and package hardness

Winding density and package hardness are very important quality parameters of the package as mentioned. In order to determine the relationship between these two parameters, an experimental study has been carried out on the winding model under the following conditions: the winding speed 800m/min, load on friction discs of the tensioner 10cN, the distance between the bobbin and the yarn guide 14cm, the pressure of package on the grooved drum 14N, winding 5 times, each time with 2 bobbin (48g/bobbin), determine the winding density Y, measure the package hardness using the Yarn Package Hardness Tester HP-5. The average hardness C of the package in table 7 is determined from 12 hardness values measured at three different diameters along the package height.

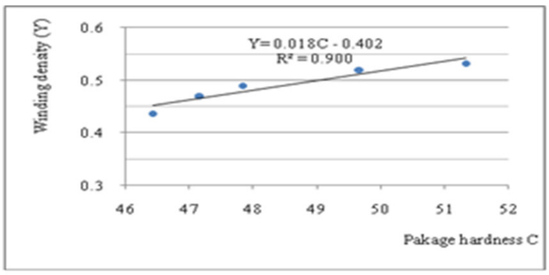
It can be seen that, when the package diameter increases, the yarn tension increases, so the winding density and package hardness increase with the diameter. By using Excel software, mathematical models were established showing the lineal relationship between winding density and package hardness (Fig. 12) with high correlation coefficient R^2 (0.948; 0.914; 0.9), proving that the calculated and experimental results are very close to each other.



a)



b)



c)

Fig. 12. Relationship between the winding density and package hardness

a) Yarn Ne 31/1 CVCD; b) Yarn Ne 30/1 CVCM; c) Yarn Ne30/1COCM

4. CONCLUSIONS

From the obtained research results, the following conclusions can be drawn:

1. Four technological parameters include: Winding speed, load on the friction discs of tensioner, distance between the bobbin and the yarn guide and the pressure of the package on the grooved drum all have effect on the winding density when winding three types of yarns Ne 31/1 CVCD, Ne 30/1 CVCM, Ne 30/1 COCM. In which, the influence of winding speed on the winding density is the largest, followed by the influence of the load applied on friction disc of tensioner on the winding density.

2. Establised mathematical models showing the relationships between winding density and package hardness, between winding density and four selected

winding parameters. The research result is the basis for selection the optimal winding parameters to achieve the required winding density or predict this quality parameter when the winding parameters have been selected.

3. In order to achieve the required winding density, there will be many options of optimal winding parameters that can be selected depending on the point of view of the user of winding machines. In this study, the optimal winding parameters (Table 6) were selected to achieve the winding density $Y_1 = 0.534g/cm^3$, $Y_2 = 0.519g/cm^3$, $Y_3 = 0.501g/cm^3$, winding speed 1000m/min in order to achieve the high productivity of winding machine when winding three types of yarn respectively.

REFERENCES

[1]. R. Senthil Kumar, "Quality requirements of Ring cop for the Modern Cone -Winding process," *Indian Textile Journal*, 2008.

[2]. MD Zahidul Islam, "Effect of Winding Speed on Yarn Properties," *Journal of Engineering Rearch and Application*, 9, 3 (Series-III), 28 - 34, 2019.

[3]. O. Talavasek, *CSc: Priprava ke tkani SNTL Praha*. 1994

[4]. Bachir Chemani, Rachild, "Theoretical Density Study of Winding Yarn on Spool," *World Academy of Science, Engineering and Technology, International Journal of Materials and Metallurgical Engineering*, 8, 10, 2014.

[5]. O. Talavasek, *Tkaní stroje clunkové, bezclunkové a vicepros-plupní*. SNTL Praha, 1998.

[6]. Gungor Durur, *Cross winding of yarn packages*. School of Textile Industries, The University of Leeds, LS29JT, 2000.

[7]. R. Fettahov, E. Tomoruk, S. Palamuteu, Hascelik., "Analysing the effect of tension to winding density and the relationship between winding density and package hardness," in *International Conference of Applied Research in Textile © CIRAT-3*, Sousse Tunisia, 2008.

[8]. Trung Tran Duc, Huong Gian Thi Thu., "Determining the effect of some technological parameters in winding process on yarn package hardness," in *Proceding of the 2nd National scientific conference on textile, apparel and leather engineering (NSCTEX 2020),* 187 - 192, 2020.

[9]. Huong Gian Thi Thu, Trung Tran Duc, "Determination of relationship between the yarn tension and some technological parameters in the winding process," *Journal of science & technology - Hanoi University of Industry*, 52, 75 – 78, 2019.

[10]. Duong Pham Duc, Chat Nguyen Van, "Study on influence of yarn tention on quality of bobbin after Dyeing," in *2-NCSTEX 2018 in Hanoi*, 2018.

[11]. M. V. Nazarova., "Optimization of the technological process of thread rewinding when forming closed-winding bobbins," *YDK 677.023.23.001.18(043.3), 3 (278) textile industry*, 2004,

[12]. Trung Tran Duc, Huong Chu Dieu, Tuan Dao Anh., "Research on new modeling of winding process for controlling yarn packagepressure on grooved drum," in *Proceding Aun/seed-net joint regional conferences in transportation, energy and mechanical manufacturing engineering - RCTEMME 2021*, 2021.

[13]. https://textiletuts.com/winding-speed-calculation/

[14]. Catalogue of Schmidt in Germany. *Yarn package Hardness Tester HP-5*.

[15]. Trung Tran Duc, Tuan Dao Anh, Huong Chu Dieu, "Influence of some winding parameters on hairiness of yarn after winding process," *Fibres and Textiles,* 29(4), 29 - 37, 2022. doi: 10.15240/tul/008/2022-4-004.