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Winding Core Spun Elastic Yarn on Cone Bobbin to be Dyed / Belforte, Guido; Ivanov, Alexandre; Maffiodo, Daniela; F., Testore. - In: JOURNAL OF THE TEXTILE INSTITUTE. - ISSN 0040-5000. - 100:(2009), pp. 412-419.
[10.1080/00405000701863319]

Availability:

This version is available at: 11583/1786395 since: 2024-06-05T13:17:11Z

Publisher:

Taylor and Francis

Published

DOI:10.1080/00405000701863319

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Winding Core Spun Elastic Yarn on Cone Bobbin to be Dyed

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Abstract

Spiral yarn composed with an elastomeric filament DOW XLA, from Dow Chemical, and wool fibres outwardly wound around the elastic core presents a complex behaviour when wounded on bobbins to be dyed. This article presents a basic mathematical model with the aim of evaluating radial pressure and transversal stress on bobbin at different angles of winding, different yarn tensions and yarn cross-section areas.

Considering the additional complexities of the real problem, an experimental comparison of bobbin alterations under different conditions was carried out with the realization of two experimental sets. The first experimental test bench allows the variation of winding tension, angle of winding and stroke, then experimental tests were carried out on a winding machine SAVIO varying yarn tension value and adding a mechanical constrain to the device with the aim of reducing yarn sliding phenomena, in particular during thermal cycle.

The fundamental parameters have been determined as the angle of wind and the yarn tension during winding operation. Higher values of wind angle help keeping the bobbin shape. Higher values of yarn tension during winding operation allow the preservation of bobbin shape after the dyeing cycle. On the other hand, the upper limit is represented by yarn tensile strength. Moreover, it's not useful to apply a varying wind tension during the winding process.

Key words

Yarn, Bobbin, Winding, Dyeing, Textiles

1 Yarn winding on cones

Winding is carried out for various purposes which include to increase package weight, to change the winding up arrangement, to change the package density, to remove yarn faults, to create a package which is not susceptible to be damaged during dyeing and subsequent drying phase [1].

The most common kind of winding is a cross-wind, a characteristic arrangement of a yarn across a bobbin, a spool or a hank, following crossing lines. The purpose is to reach a stable mechanical structure, that doesn't allow yarn entangling between different layers [2].

Referring for simplicity to a cylindrical shape, an external winding has nearly sinusoidal shape and, theoretically, it is out of phase with the coils lying beneath. Yarns cross one another and friction guarantees a stable "x-structure".

Characteristic parameters are:

- Yarn tension;
- Angle of winding [3];
- Bobbin diameter;
- Yarn guide (or cylindrical cam) stroke [4];
- Cradle pressure, the force acting between bobbin and drive roll (in case of cylindrical cam winding machine).

Important bobbin problems are the so called "ribbons", a critical zone where yarn density is too high, and the yarn on the sides of the package. It is important to prevent loose portions of yarn from lying parallel to the sides.

This kind of problem presents additional complexities for elastic yarns because of the presence of a synthetic elastomer. During the dyeing cycle this elastomer varies its characteristics, and this causes serious modifications on the bobbin structure coming out from the dye bath.

Recent researches aim to increase the knowledge about the behaviour of these core spun elastic yarns. Kakvan *et al.* [5] investigated the physical properties of a Spandex filament; Babay *et al.* [6] refer the importance of elastane ratio on the mechanical properties of such a yarn; Lou *et al.* [7] designed and investigated a polyester core spun yarn containing spandex fibers.

Since this problem presents some difficulties and unknown aspects in case of spiral yarn composed with an elastomeric filament DOW XLA, from Dow Chemical, and wool fibres outwardly wound around the elastic core, this article represents a contribution to solve the problems of yarn winding on dyeing bobbins in presence of an elastic filament. Starting from a mathematical model, experimental tests were made to identify the effects of winding parameters during dyeing.

2 Mathematical model of an elastic yarn bobbin

A simplified model of yarn bobbin with negligible friction and inextensible yarns was made in order to have general information about the influence of basic geometrical parameters.

Referring to an industrial bobbin, showed in fig 1, the yarn is wound with a constant and well-known cross-wind angle. At the sides there are visible areas where the yarn is nearly at right angles to the winding axis, but in a wide central area the structure looks regular.

In the first instance, it is possible to build a model with the hypothesis that yarn is inextensible. Besides, it is possible not to calculate the friction, but to consider the system of forces rising from the yarn tensioning as predominant. These significant simplifications will require a necessary evaluation of their implications.

To build a model of industrial bobbin some geometric parameters were introduced (fig. 2):

- the cross angle γ , defined as the angle between the yarn tangent line and the surface orthogonal to the bobbin axis;
- the bobbin radius r ;
- the bobbin height H .



Figure 1 An industrial bobbin

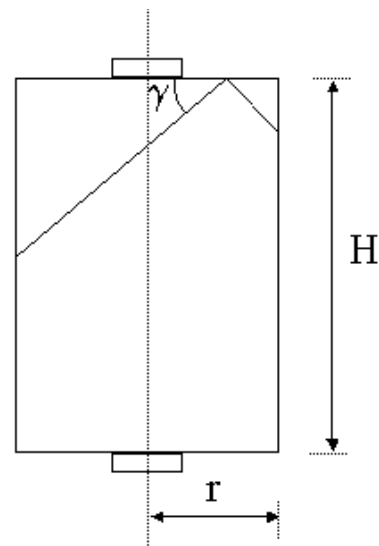


Figure 2 Bobbin scheme

Furthermore, to calculate the internal stress, we define two auxiliary parameters below described. Referring to figure 3, the effective area A_{eff} is determined making a single layer section (A-A) of the bobbin, orthogonal to the yarn direction in that layer. In such a way, we orthogonally intercept all the yarns composing the layer (black circles, fig 3). The real complete section is an

ellipse that can be rectified to obtain a rectangular area (grey area, fig 3) having a width equal to the yarn diameter and a length equal to the length of the determined section. The rectangle area divided by the number n of intercepted yarns is called the effective area A_{eff} .

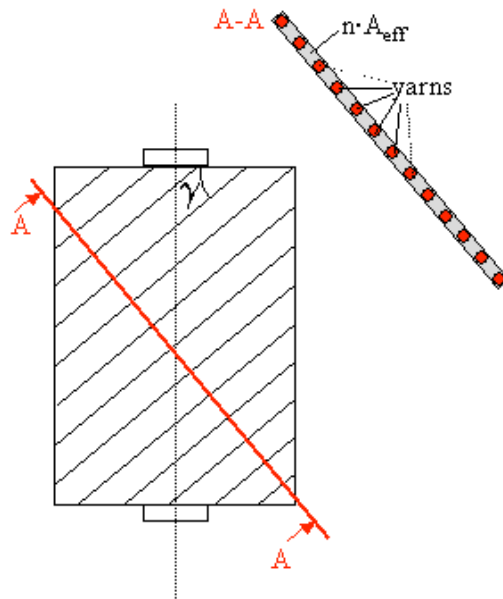


Figure 3 Bobbin scheme and effective area.

The second auxiliary parameter definition is referred to figure 4, a view of the bobbin from the top. We hypothesise to wind the yarn around a polygonal surface inscribed on the circle having radius r , instead of the winding around the circle. The polygon has m sides and α is the central angle that subtend a polygon side. Therefore the angle α is defined as:

$$\alpha = \frac{2\pi}{m}$$

The angles β in point A e B are expressed by:

$$\beta = \frac{\pi - \alpha}{2}$$

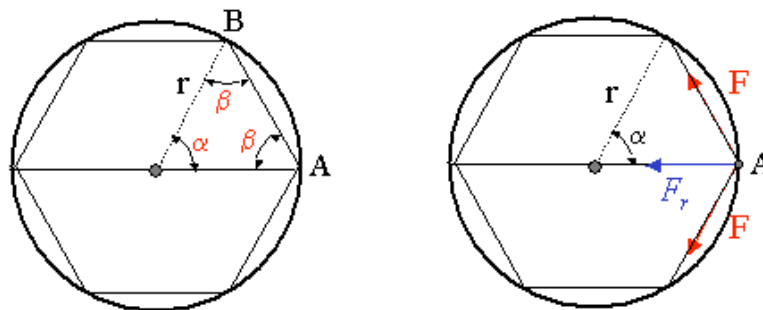


Figure 4 a) definition of parameters α e β ; b) system of forces acting in point A .

Considering the forces, the bobbin model considers the contemporaneous presence of two effects: the pressure increase inside to the bobbin caused by the preload tension of the yarn and the transversal load allowing to keep bobbin shape constant.

Considering the yard winding around a m -sides polygon inscribed on the circle and the preload F .

A component F for each polygon side acts on the yarn in point A, resulting in a force F_r equal to:

$$F_r = 2 \cdot F \sin\left(\frac{\pi}{m}\right)$$

To evaluate the overall linear p_{ll} pressure acting on the bobbin circumference, it is necessary to calculate the limit toward which this radial force divided by the circumference length goes as the variable m approaches infinity:

$$p_{ll} = \lim_{m \rightarrow \infty} \left(\frac{m \cdot F_r}{2\pi r} \right) = \frac{F}{r} \quad (1)$$

Actually, it is necessary to consider the yarn direction on the bobbin: referring to figure 5, it can be seen that cross-winding impose an angle to the yarn. Then preload force F_0 imposed to the yarn by the winding machine has the same cross-winding angle. Thus the preload component acting orthogonally to the bobbin axis is $F_0 \cos \gamma$. The previous equation becomes:

$$p_{ll} = \frac{F_0 \cos \gamma}{r}$$

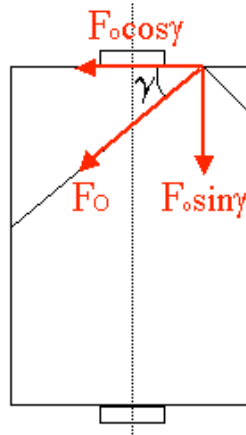


Figure 5 Yarn preload force components along bobbin axis and transverse direction.

Therefore it is necessary to determine a law for pressure as a function of bobbin radius. Making a cross-section of the bobbin, we obtain the scheme of figure 6. We consider the radius increase Δr , from r to $(r + \Delta r)$ and the corresponding pressure variation.

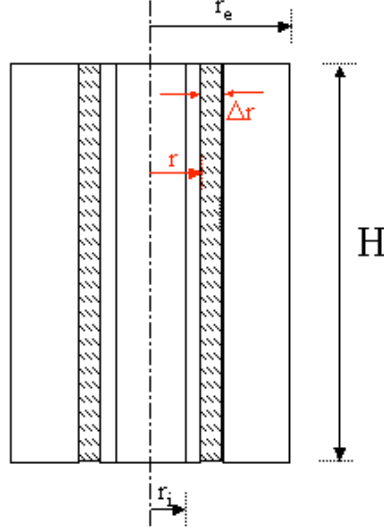


Figure 6 Bobbin cross section

Maximum number of yarns intercepted by the cross section, restricted to radial extension Δr , can be determined remembering the auxiliary parameter A_{eff} . It is referred to a section orthogonal to the yarn owing to a single layer. Thus it is possible to make a projection of this area on the cross-section to determine the effective area referred to the cross section $A_{eff}/\cos\gamma$.

The requested number of yarns N_1 is the ratio between the section area $H\Delta r$ and the effective area referred to the cross section $A_{eff}/\cos\gamma$:

$$N_1 = \frac{H \cdot \Delta r \cdot \cos \gamma}{A_{eff}}$$

We consider the radius increase Δr , from r to $(r + \Delta r)$ and the corresponding pressure variation.

The linear pressure increase as a function of the radius increase from r to $r + \Delta r$ is the product between linear pressure p_{ll} and the number of yarn layers inside the cross-section having radial width Δr . To obtain the overall surface pressure variation it is necessary to divide the linear pressure increase by the bobbin height:

$$\Delta p = \frac{p_{ll} \cdot N_1}{H} = \frac{F_0 \cos^2(\gamma) \cdot \Delta r}{A_{eff} \cdot r}$$

The known boundary condition, imposing relative pressure equal to zero at the external radius r_e , allows to integrate the previous function and reach the desired expression for the radial pressure:

$$p(r) = \frac{F_0 \cos^2(\gamma)}{A_{eff}} \ln\left(\frac{r_e}{r}\right) \quad (2)$$

Similarly it is possible to consider the effect of the axial component of the yarn preload force, equal to $F_a = F_0 \sin\gamma$, see figure 5.

Figure 7 represents a section orthogonal to the bobbin axis. Maximum number of yarns intercepted by this section, restricted to radial extension Δr , can be determined as above, projecting the effective area on a perpendicular surface and obtaining an area of $A_{eff}/\sin\gamma$. Number of yarns N_2 is the ratio between section area $2\pi r \Delta r$ and effective area on this section:

$$N_2 = \frac{2\pi r \Delta r \cdot \sin \gamma}{A_{eff}}$$

The transversal stress can be expressed by the overall force divided by the section area

$$T = \frac{F_0 \sin \gamma \cdot N_2}{2\pi r \Delta r} = \frac{F_0 \sin^2 \gamma}{A_{eff}} \quad (3)$$

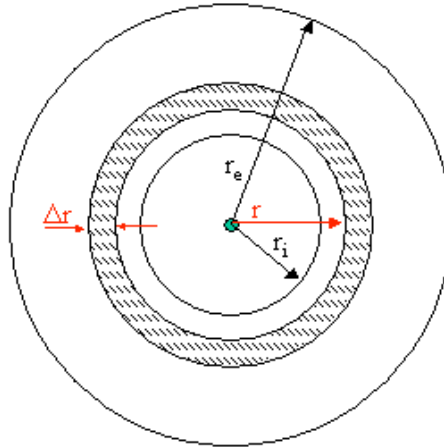


Figure 7 Section with a plane forming straight angle with bobbin axis

Varying parameter values on formulas (2) e (3) allows to simulate the bobbin behaviour in different conditions, as an example see figure 8.

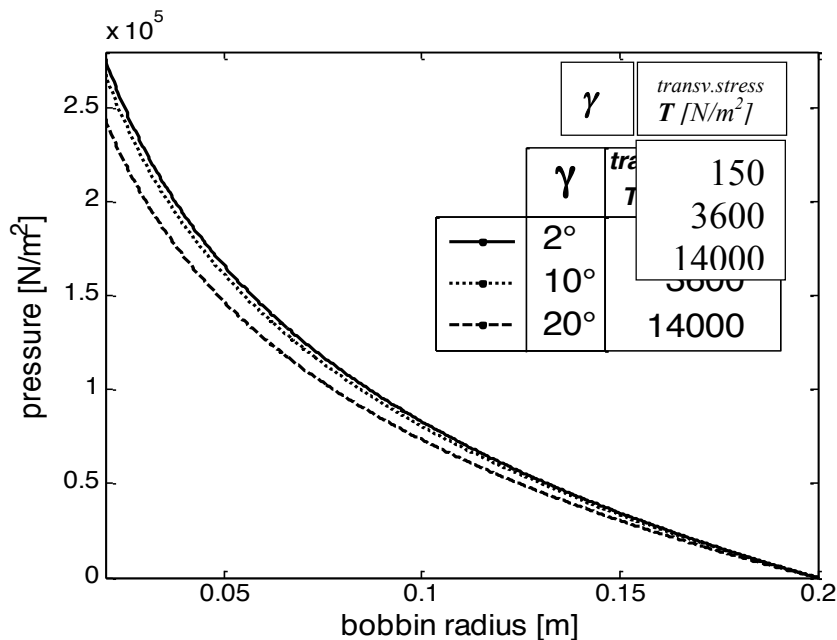


Figure 8 Bobbin radial pressure and transversal stress with $F_0 = 12$ cN and $A_{eff} = 1$ mm²

4 Experimental set

Mathematical models offer preliminary evaluations but, considering the additional complexities of the real problem, it was decided to carry on with an experimental comparison of bobbin alterations under different conditions.

Indeed, the presence of hardly measurable parameters (e.g. yarn internal friction, non-homogeneity, anisotropy) is nearly impossible to implement inside the model. Various non-linear parameters would be obtained from a yarn mechanical characterization, since there are two different constituent elements with different thermo-mechanical characteristics.

Difficulties of a complete model, uncertainties of model results for situations that are not those for validation, the presence of unevenness at bobbin sides, the complexities of the thermal cycle led to an experimental testing.

The experimental test bench (figure 9) allows the variation of the following parameters:

- winding tension,
- angle of winding,
- stroke.

Particularly, the winding tension has a feedback control. It prevents invernences thanks to a force sensor and the comparison between its measure and a desired force value.

The bobbin obtained with this winding machine is then subjected to a thermal cycle equivalent to a dyeing cycle.

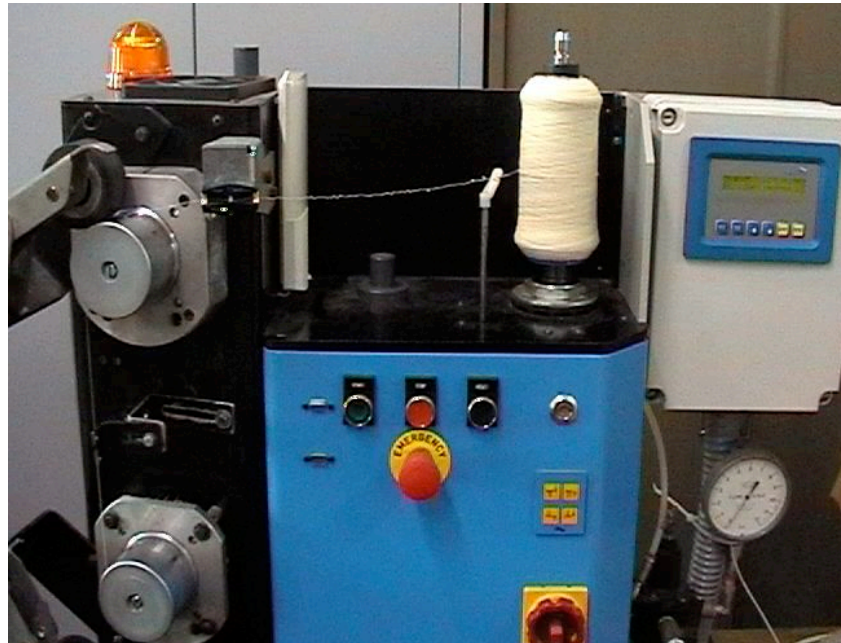


Figure 9 The experimental test bench

First experimental set

With the above described bobbin machine, we made 7 different bobbin groups, described in table 1.

Each test was carried out with the above mentioned wool yarn with elastomeric core.

Bobbin characteristics are described in Table 1, where “standard winding angle” is above 10°.

Table 1

<i>Bobbin</i>	<i>Yarn tension [cN]</i>	<i>Cross-wind angle</i>	<i>Mass [g]</i>
1	12	Standard winding angle	240
2	5	Standard winding angle	240
3	17	1/5 of standard winding angle(above 2°)	240
4	5	Double winding angle (above 20°)	240
5	17	Standard winding angle	240
6	12	Double winding angle (above 20°)	240
7	12	Double winding angle (above 20°)	480

After winding each bobbin had a regular structure; after a thermal cycle corresponding to the dyeing cycle aspect could vary quite a lot.

The thermal cycle consists of 30 minutes at 98°C, with 100% humidity.

In this first testing set all bobbins have been subjected to the thermal cycle without additional constraint at their sides. This condition, different from real dyeing conditions, was chosen to emphasize thermal cycle influence on the elastic filament and to highlight the influence of parameters (winding angle, yarn tension, mass) on bobbin behaviour.

Figure 10 represents the seven bobbins after thermal cycle.

Bobbin 1 presents sides tapering caused by an undesired layer sliding during the thermal cycle.

Bobbin 2, compared to 1, only differs for the yarn tension. This leads to a higher tapering, corroborating the hypothesis that a lower tension helps yarn sliding.

Bobbin 3 shows that decreasing winding angle leads to quite bad results. We didn't continue on this way.

Bobbin 4 is similar to 2, but with a double cross winding. It has better behaviour, although there are evenesses on the sides.

Bobbin 5, having triple yarn tension compared to bobbin 2, demonstrates that bobbins made with higher yarn tension undergo thermal cycle without important structural modifications.

Comparing bobbin 6 and bobbin 1 with bobbin 4 and bobbin 2, it can be observed that bobbin 6 is worst than bobbin 4, then having a double cross winding could imply a lower tension to have better results.

Doubling the mass, from bobbin 6 to bobbin7, leads to worst results because of the presence of sliding, but the bobbin shape is better.

Resuming the first experimental set, it seems useful a higher cross winding and yarn tension.

We carried out also experiments with a yarn tension variable along the bobbin, but it doesn't seem to be useful.

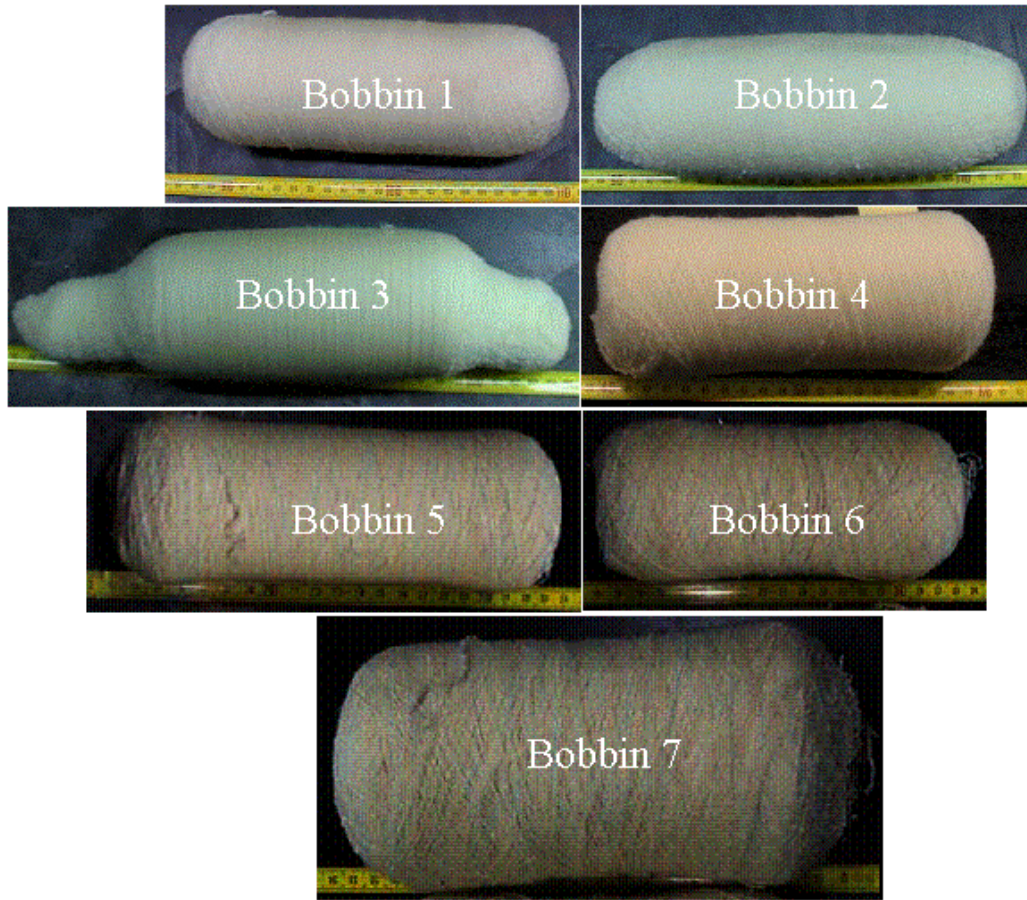


Figure 10 Seven bobbins after thermal cycle

Second experimental set

To verify the results obtained with the testing winding machine on an industrial winding machine, we made experimental tests on a winding machine SAVIO (figure 11), varying yarn tension value and adding a mechanical constrain to the device, two metal opposite circular bases at the bobbin sides, with the aim of reducing yarn sliding phenomena, in particular during thermal cycle.

Unlike the experimental machine, working with reciprocating yarn guide, Savio industrial winding machine works with cylindrical cams. For this reason we couldn't vary the cross-winding angle, fixed by the cam shape.

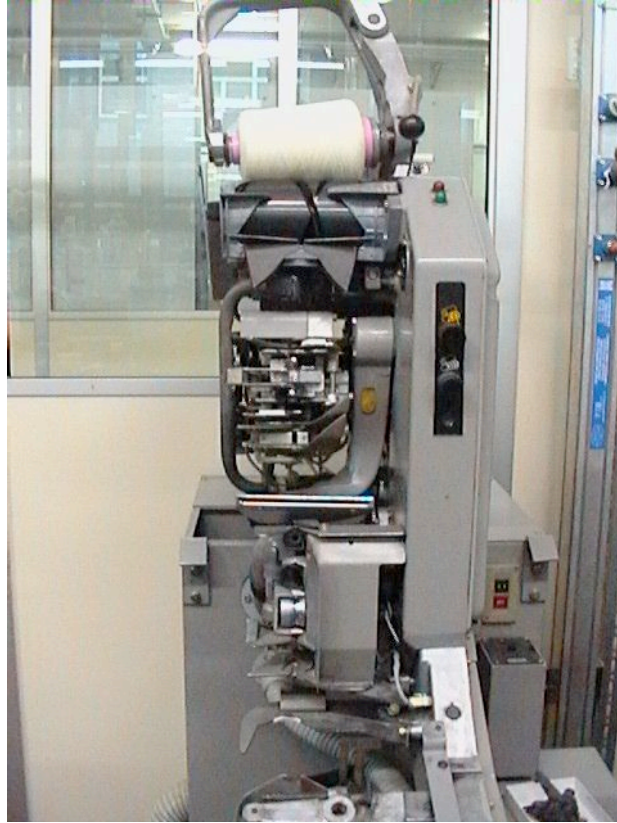


Figure 11 SAVIO winding machine

Savio winding machine has an arbitrary scale (t) to measure the yarn tension. In any case, two bobbins having same weight (500 grams) and different yarn tension ($t=2$ or $t=10$) (figure 12) show that the higher is the tension, the better is bobbin structure and the less the bobbin shape varies during the thermal cycle.

Figure 13 shows two bobbins having same weight (500 grams), same tension ($t=2$), made with or without metal opposite circular bases. It is evident the restraint imposed by metal opposite circular bases, looking the left bobbin which has regular sides.

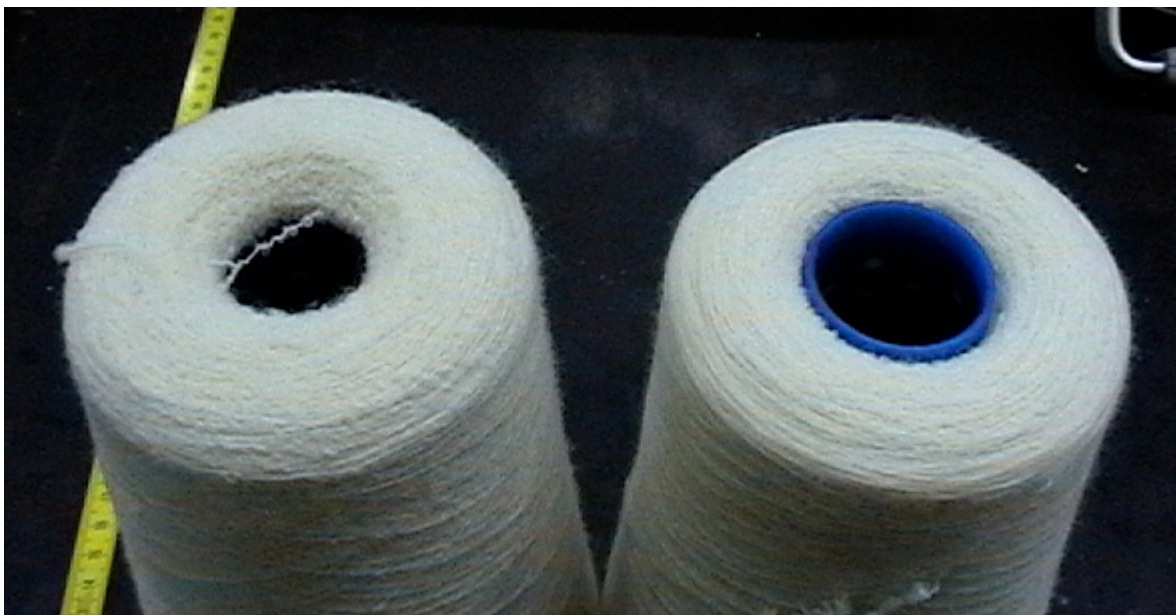


Figure12 Bobbin with $t=2$, left, and $t=10$, right, after thermal cycle.



Figure 13 Bobbin obtained with metal opposite circular bases, left, without metal bases, right, after thermal cycle.

4 Conclusions

Problems related to dyeing cycle of a worsted yarn spun with an elastomeric core, made of a filament *DOW XLA* from *Dow Chemical*, have been studied with both analytical models and experimental tests.

A correct bobbin winding is an essential requirement to avoid risks of uneven tensions and yarn breakages during unwinding.

The fundamental parameters have been determined as the angle of wind and the yarn tension during winding operation. Higher values of wind angle help keeping the bobbin shape. Higher values of yarn tension during winding operation allow the preservation of bobbin shape after the dyeing cycle. On the other hand, the upper limit is represented by yarn tensile strength

Moreover, it came out that it's not useful to apply a varying wind tension during the winding process.

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