A geometrical assessment of the dimensional properties of interlock knitted structure

H. Dabiryan[a], Ali A. A.Jeddi[b]

[a] *Technology of Textile Research Group, Iranian Center for Education, Culture and Research (ACECR), Branch of Amirkabir University of Technology, Tehran 15914-Iran*

[b] Department *of Textile Engineering, Amirkabir University of Technology, Tehran 15914, Iran*

Abstract

Geometrical models of full-relaxed interlock knitted structure are proposed in this investigation for two and three dimensional forms. It was assumed that the face loops in plain and interlock structures are similar. Therefore, the strophoid classical curve, which was considered as a function of an ideal model for a plain knitted structure, was taken and improved as the first segment of structural knit cell (SKC). Another segment of SKC, i.e, the linking portion between face and back loops, explained by a quadratic equation. From these models, the Us value as an important constant dimensional value was obtained and compared with the measured Us value that was taken from the experimental work of previous researcher. Finally a good agreement was observed between the theoretical and experimental results.

Keywords: Ideal model, Interlock structure, dimensional stability, minimum internal energy, knitted fabric

1.Introduction

The geometry of interlock structure has received comparatively little attention. Knitting loop geometry is the key element in understanding the dimensional behavior of knitted fabrics. In the theoretical studies of knitted fabric dimensions, emphasis has mostly been placed on defining the shape of the loop. Fabric dimension, on the other hand, are directly related to those of a unit cell defined by joining similar points of loops in adjacent wales and courses. One of the major successes of the scientific approach to the study of the knitting process has been the realization of the importance of loop length (Doyle, 1953,). This fundamental parameter, governing most fabric properties, is defined as the length of yarn in the smallest repeating unit of the structure. From the above concept, Munden (1959) was able to derive four non-dimensional parameters or K-values, governing the dimensions of plain knitted fabrics. Knapton et al (1968) modified Munden's K-values by using the following definitions. The effective loop length should be the length of yarn in one structure knitted cell (SKC), defined as the smallest repeating unit of the structure (L_u). Course units per unit fabric length (C_u), wale unit per fabric width (W_u), and the number of SKC's per unit area (S_u). For example, the SKC of an interlock structure consists of four single loops. From the above definition, they presented the following non-dimensional parameters for complex weft-knitted structures:

$$U_c = C_u \times L_u \quad (1)$$

$$U_w = W_u \times L_u \quad (2)$$

$$U_s = S_u \times L_u^2 \quad (3)$$

$$\frac{U_c}{U_w} = \frac{C_u}{W_u} \quad (4)$$

Dimensional stability in knitting fabrics can be attained by either mechanical relaxation or chemical treatments. Knapton et al (1975) indicated that both mechanically and chemically treatments must act very largely through the same fundamental mechanism. Munden (1959) suggested that in a fully relaxation state, the knitted fabric loop takes up a geometrical shape to establish a state of minimum internal energy. In the fully relaxed state when the fabric is released from mechanical strains, the loop will tend to take up the ideal shape, and the maximum shrinkage is obtained for fabric (Semnani, *et al.,* 2003). For this reason, we have suggested (Jeddi and Zareian, 2006, Mohammadi and Jeddi, 2006) the ultrasonic waves technique as a new method for relaxation processing to release more forces imposed on the yarn during knitting. In our recent research (Jeddi, et al. 2006) to consider knitted fabric relaxation by using ultrasound technique, we concluded that the Munden's suggestion (1959), i.e. "The yarn within a fully relaxed fabric structure assume a minimum energy shape" is not generally acceptable. But it should be expressed that, the plain knitted fabric constructed from cotton yarn within a fully relaxed fabric structure assume an optimum energy shape as such as reach to a maximum shrinkage.

In the previous papers of this series (Jeddi *et al., Int. J. Eng*., 12, 39-40, 1999, Semnani *et al*., *J. Text. Inst.*, 94(1), 204-213, 2003, Jeddi and Zareian, 2006), we presented theoretically ideal models for the plain knitted loop and 1×1 rib knitted structure based on the new approach of geometrical and physical principles. The analysis was introduced for two and three-dimensional models. Then to obtain the natural or ideal configuration of the knitted loop with the conditions of minimum energy, we use the ultrasonic wave to decrease the potential energy of the fabrics. In this study we attempt to develop this kind of ideal model for interlock structure. Then by using conventional mechanical relaxation and ultrasonic relaxation treatment, the obtained non-dimensional parameters of the fabric (Uc, Uw &Us values) are measured and compared with the theoretical values.

2. Theoretical Analysis

Interlock has the technical face of plain fabric on both sides (Spencer, 1983) but its smooth surface can not be stretched out to reveal reversed meshed loop wales because the wales on each side are exactly opposite to each other and are locked together (Fig.1).

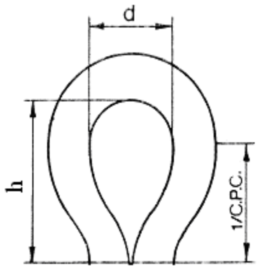

Fig.1. The loop model geometry of plain structure.

each interlock pattern row (Often termed an 'interlock course') requires two feeder courses each with a separate alternate needles producing two half-gage 1×1 rib courses whose sinkers loops cross over each other.

In derivation of the ideal stitch model for interlock knitted fabric in an ultimate full-relaxed structure with an optimum internal energy (Munden, 1959), the following assumption are made for both two and three dimensional models:

(i) the face loop in plain and interlock structures are similar.

(ii) the shape of structural knitted cell (Fig.1 and Fig.3) is divided into two segments, one segment being the needle loop and two arms of four plain-type face loop of cell (Fig.2) which follows the mathematical based equation of improved Strophoid curve. Another segment is the linking portions between face and back loops.

(iii) Loops of adjacent wales touch at their widest parts. Also, the consecutive courses make contact with each other and the arms of the loop make contact at the point of the minimum loop width, i.e. both length and width jamming of structure occurs in the fabric.

(iv) The narrowest and widest parts of any two interlocking loops in the same wale coincide, that is in agreement with Munden's assumption (1959).

(v) The yarn is assumed to behave as a cylindrical elastica rod and follows the elastica property (Leaf, 1958).

2.1. Construction of two-dimensional

The needle loop and two arms of four plain-type face loops of the structural knitted cell for interlock fabric is shown in Figure 2.

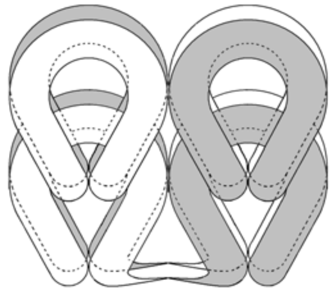

Fig. 2. The geometrical configuration of interlock structure.

Since this segment of cell is assumed similar to plain-type face loops of the structural cell of 1×1 rib fabric (Jeddi and Zareian, 2006), thus a brief description of its formula is given here. The equation of the improved strophic curve for this segment is as follows:

$$y^2 = \frac{h-x}{h+2.5x} \times x^2 \qquad (5)$$

where *h* is the maximum height of the loop.

The extermum points of this function occur at:

$$x_{\max} = 0.584429h \qquad (6)$$

$$y_{\max} = \pm 0.24015h \qquad (7)$$

Thus the maximum width of the loop model is determined as:

$$d = 2.y_{\max} = 0.4803h \qquad (8)$$

To calculate the needle loop and two arms, we used parametric equation (5). The definite integration was solved using Simpson's method with n=100. Finally the numerical value of the length of the needle loop and two arms (L_{plain}) was obtained by using the computer program (Jeddi and Zareian, 2006) as follows:

$$L_{plain} = 2.34692(h + \frac{D}{2}) \qquad (9)$$

where D is yarn diameter.

Structure cell stitch length (L_u)

The structural cell stitch length of interlock fabric can be calculated by referring to figures 1and 3 as following:

$$L_u = 4L_{plain} + L_{links} \qquad (10)$$

By assuming that the same moment force imposed on the two ends of the linking portion between face and back loops (P and Q in Fig.3), and O is support, therefore OP follows a quadratic equation according to:

$$y = a.x^2 \qquad (11)$$

$y_p = Cot\theta . x_p$, then $a = \frac{Cot\theta}{x_p}$. Hence from equation (11):

$$y = \frac{Cot\theta}{x_p} \cdot x^2 \qquad (12)$$

By using Decartian method to calculate the length of Arc OP, we have:

$$\begin{cases} S_{AB} = \int_a^b (1+y'^2)^{1/2}.dx \\ y = f(x), a \le x \le b \end{cases}$$

$$S_{op} = \int_0^{x_p} \left\{ 1+(\frac{2.Cot\theta}{x_p}.x)^2 \right\}^{1/2} .dx \qquad (13)$$

Assume that:

$$\frac{2.Cot\theta}{x_p}.x = k \Rightarrow dk = \frac{2.Cot\theta}{x_p}.dx \Rightarrow dx = \frac{x_p}{2.Cot\theta}.dk$$

$$\begin{cases} x=0 \Rightarrow k=0 \\ x=x_p \Rightarrow k=2.Cot\theta \end{cases}$$

Therefore:

$$L_{op} = \frac{x_p}{2.Cot\theta} \int_0^{2.Cot\theta} \left\{ 1+k^2 \right\}^{1/2} .dx \qquad (14)$$

From Figure 3 we have:

$$y_p = \frac{T-2D}{2} \qquad (15)$$

$$\tan\theta = \frac{3D}{2.y_p}$$

where T is fabric thickness.

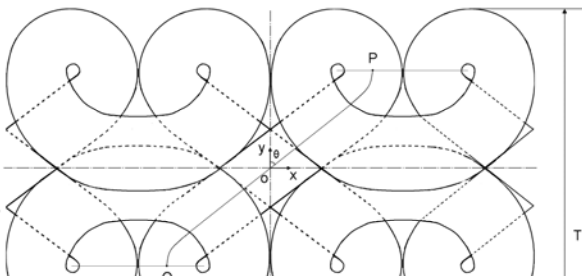

Fig.3. Plan view of interlock structure.

From the general geometrical model of Postle (1974), base on the assumption of a constant unit-cell configuration for a particular knitted construction, the ratio of the geometrical fabric thickness (T), to the effective yarn diameter (D), for interlock structure is 4.1. Therefore, $y_p = 1.05D$ and $x_p = 1.05D \times \tan\theta$. From Fig.3, θ can be calculated as following:

$$\tan\theta = \frac{3D}{2.(1.05D)} \Rightarrow \theta = 55^\circ$$

Then we have:

$$L_{op} = \frac{1.4995D}{2.Cot55} \int_0^{2.Cot55} \left\{ 1+k^2 \right\}^{1/2} .dx \qquad (16)$$

By using this estimation, and Mathematica 4 software, the Equation (16) was solved as follows:

$$L_{op} = 1.8993\ D \qquad (17)$$

We have:

$$L_{links} = 8\,L_{op} = 15.1944D \qquad (18)$$

And finally:

$$L_u = 9.38768h + 19.889D \qquad (19)$$

The constant dimensional parameters (U_c, U_w *and* U_s)

From Postle's work (1974), the value of the ratio T/L_u for interlock fabrics, becomes 0.0569. Therefore: $D = 0.013889L_u$, and finally:

$$h = 0.0771\,L_u \qquad (20)$$

From Figure 2, the maximum width and length of the structural knit cell for interlock fabrics can be calculated as follows (A knit cell of interlock fabric is two times of knit cell of plain fabric):

$$W_u = \frac{1}{2[d+2D]} = \frac{7.715}{L_u} = \frac{U_w}{L_u} \qquad (21)$$

$$C_u = \frac{1}{x_{max}} = \frac{22.19}{L_u} = \frac{U_c}{L_u} \qquad (22)$$

$$S_u = W_u \times C_u = \frac{171.196}{L_u^2} = \frac{U_s}{L_u^2} \qquad (23)$$

2.2. Construction of three-dimensional model

A similar manner to plain knitted fabric model was adopted (Semnani et al, 2003) to extend two-dimensional analysis to three-dimensional. Figure 4 shows a side view of the three-dimensional loop structure. The same assumptions outlined in the plain knitted model are applied here. Therefore, the length of arc AB is the same as the height of the loop at two-dimensional model state i.e. AB = h + D/2, and the wale spacing is identical to that model. It should be noted that, there is nearly 1.8% difference between the true arc (AB) of the yarn follows the path of a deformed elastica, and a part of a circle (EF) plus two straight lines (AE and FB). If it is assumed that $\alpha = \pi/6$ and AE = FB, the fabric dimensional parameters are evaluated for the three-dimensional structure by using Strophoid equation as follows:

$$\frac{1}{C_u} = QK + KB = 1.5D + KB \qquad (24)$$

$$Sin\beta = Sin(\frac{\pi}{2} - \alpha) = \frac{FK}{OF} = \frac{FK}{D} \Rightarrow FK = D.Cos\alpha = 0.01203 L_u$$

$$arcEF = 2D.2\alpha = 2.094D$$

$$FB = AE = 0.5h - 0.797D = 0.02748 L_u$$

$$KB = \sqrt{FB^2 - FK^2} = 0.024698 L_u$$

Therefore:

$$C_u = \frac{U_c}{L_u} = \frac{21.96}{L_u} \quad (25)$$

$$S_u = \frac{U_s}{L_u^2} = \frac{169.44}{L_u^2} \quad (26)$$

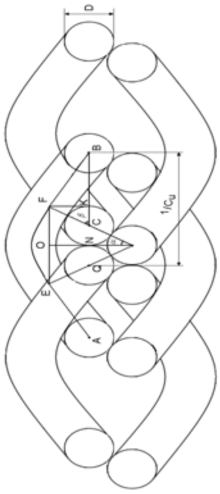

*Fig. 4.*A side view of the three-dimensional interlock structure.

3. Comparison between theoretical model and experimental results

To compare the theoretical non-dimensional parameter or U_s Value achieved in this method with experimental results, we used the experimental U_s values which were studied by Anand et al (2002). They investigated the effect of laundering on the dimensional stability of three popular 100% cotton knitted fabrics (plain single-jersey, 1×1 rib and interlock). These fabrics were subjected to five cycles of four different washing and drying regimes. The fabrics had taken up their fully relaxed dimensions after five wash and dry cycles and appropriate conditions for launderings had been applied. The average length of yarn in a single loop of interlock structure and its stitch density were measured respectively 0.270 cm and 301.1 loops per square centimeter. Therefore, the smallest repeating unit length yarn of the structure is L_u=1.08 cm, and the number of structure knit cell per cm^2 is S_u= 150.55. Consequently, the experimental U_s value becomes 175.60. Therefore, the experimental U_s value shows a little difference from theoretical values (2.5% higher than two-dimensional model and 3.5% higher from three-dimensional model).

4. Discussion and Analysis

The aim of expression of the experimental data from other researcher is to compare their U_s value with the theoretical U_s value which is calculated from the ideal model of interlock structure. The experimental data for interlock fabric is obtained in a full relaxation state. It is showed that there is a small difference between the theoretical model and the experimental U_s values. This difference may be attributed to the variations of the empirical measurement or to the some unreal theoretical assumptions. This small difference confirmed that this ideal model is a useful prediction method for interlock dimensions in its complete stability state. On the other hand, interlock has a more balanced structure, and so a dimensional stability occurred when the fabric was subjected to agitation during drying. This confirms that in interlock structure, the loops had taken up their fully relaxed dimensions after five wash – dry cycles. Hence, no another advanced relaxation technique, such as ultrasonic wave's method (Jeddi and Zareian, 2006) appear necessary to reach the fabric stabilization to a higher degree.

5. Conclusion

Similar to the theoretical analysis for plain and l×l rib knitted structures in our previous publications (Jeddi et al, 1999,2003, and 2006), we presented in this paper an ideal model for interlock structure. We assumed here that the face loops in plain and interlock structures are similar. Therfore, this segment of structural knit cell (SKC) follows the equation of improved strophoid curve and another segment of SKC, i.e, the linking protion between face and back loops, explained by a quadratic equation. Then, the theory was extended to a three dimensional model.

For both models, the fabric dimensional parameters were estimated. The experimenal value of U_s parameter which was obtained by previous researcher in fully relaxed interlock structure reveals a good agreement with the theoretical U_s values. In conclusion, we can confirm that this ideal model is a suitable method to predict the constant dimensional parameters of interlock structure in fully-relaxed state.

References

[1] Anand, S. C., Brown, K. S. M., Higgns, L. G., Holmes, D. A., Hall, M. E., and Conrad, D., 2002. Effect of laundering on the dimensional stability and distortion of knitted fabrics, *AUTEX Res. J.*, 2, 85-100.

[2] Doyle, P. J., 1953. Fundamental aspects of the design of knitted fabrics, *J. Textile Inst*., 44, p561-578.

Jeddi, A. A. A., Hamzeh, S., and Latifi, M., 1999. A comparative theoretical analysis for a knitted loop model. *Int. J. Eng*., 12, 39-44.

[3] Jeddi, A. A. A., and Otaghsara, M. R. T., 1999. The effect of yarn twist and fibre percentage in blends on the dimensional properties of the interlock structure, *J.Textile Inst.* 90. 541-554.

[4] Jeddi, A. A. A., Mommadi, V., Rahimzadeh, H., and Honarvar, F., 2006. Knitted fabric relaxation by ultrasound and its characterization with yarn- pullout force. *Indian J.Fibre Textile Res*., (in press).

[5] Jeddi, A. A. A., and Zareian, A., 2006. Ideal model for 1×1 rib fabric with taking into account of yarns swelling, a guidance to use of ultrasonic relaxation method. *J. Textile Inst*., 97, 1-8.

[6] Knapton, J. J. F., Ahrens, F. J., Ingenthron, W. W., and Fong, W., 1968. The dimensional properties of knitted wool fabrics Part II:

1×1, 2×2 Rib, and half – cardigan structures, *Text. Res. J.,* 38, 1013-1026.
[7] Knapton, J. J. F., Truter, E. V., and Aziz, A. K. M. A., 1975. The geometry, dimensional properties, and stabilization of the cotton plain – jersey structure. *J.Textile Inst.*, 12, 413-419.
[8] Leaf, G. A. V., 1958. A property of a buckled elastic rod, *Br. J. Appl. Phys*., 9, 71-72.
[9] Mohammadi, V., and Jeddi, A. A. A., 2006. Dimensional stabilization of cotton plain knitted fabric by using ultrasonic waves. *Indian J.Fibre Textile Res*., 31(2), 339-341.
[10] Munden, D. L., 1959. The geometry and dimensional properties of plain knit fabrics, *J.Textile Inst*., 50, T448-T471.
[11] Postle, R., 1974. A geometrical assessment of the thickness and bulk density of weft – knitted fabrics, *J. Textile Inst*., 65, 155 – 163.
[12] Semnni, D., Latifi, M., Hamze, S., and Jeddi, A. A. A., 2003. A new aspect of geometrical and physical principles applicable to the estimation of textile structures: Ideal model for plain knitted loop. *J.Textile Inst*., 94, part 1, 204-213.
[13] Spencer, D. J., 1983. Knitting Technology. Pergamon Press Ltd, Headington Hill, Hall, Oxford OX3 OBW, England.