NC STATE UNIVERSITY

JTATM

JOURNAL OF TEXTILE AND APPAREL, TECHNOLOGY AND MANAGEMENT

Volume 5, Issue 2, Summer2006

Dynamic Fatigue of Plain Knitted Fabric

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ABSTRACT

A new dynamic fatigue tester simulating knitted fabric deformation during use is proposed in this paper. An image processing device was developed and used to model the loop geometry of a plain knitted fabric. Based on the analysis of existing plain knitted fabrics, the geometrical modelling of knitted loop propose the combination of different mathematical functions to describe the loop geometry. A plain knitted fabric made of cotton commonly used in the clothing industry was tested with the fatigue device at different cycles and then relaxed. Repeated elongation involved permanent deformation depending on relaxation and number of cycles. The origins of dimensional behaviour of knitted fabric after fatigue test were discussed.

Keywords: fatigue test, plain knitted fabric, image processing, permanent deformation, relaxation

1. Introduction

Plain weft knitted fabrics from cotton are very popular in clothing industry. Cotton, being a non thermoplastic fibre, is unable to be heat set. Dimensional properties of this category of knitted fabric is widely affected by external applied forces that could involve permanent deformations. Repetitive elongation is a very common form of deformation in textile materials and especially in knitted structures. Knitted fabrics employed in clothing undergo a very large number of elongations when putting the apparel on or during body motion. The loss of elasticity during use is one of the most important problems that could affect the long-term reliability of knitted garments such as underwear and sportswear.

At present, there is no any standard or official procedure permitting to measure permanent deformation involved by a very high number of cyclic elongations that simulates the use of a knitted garment. Several works in the past have examined the dimensional behaviour of knitted fabrics at rest or under constant forces. The key element is the geometry of the knitted loop. Pierce [12], Leaf [7,8,9], Doyle [4,5], Munden [11], Postle [14], Derminoz *et al.* [3], Araujo *et al.* [1], Semnani *et al.* [15] and Choi *et al* [2] have significantly contributed to the geometric analysis of plain knitted fabric. But in most cases, the plain knitted fabric was described with very simple geometrical shapes such as arcs of circle and segments.

Alternatively the dimensional properties of knitted fabrics were studied by some researchers using the force method. In the theoretical models of Postle *et al.* [13], and Hepworth *et al.* [6] yarn was treated as a perfectly elastic structure that is naturally straight. A theoretical work accomplished by MacRoy *et al* [10] attempted to describe load–extension phenomenon of plain knitted fabrics. MacRoy's Model emphasized slippage between loops and applied load with loop elements being straightened.

We propose to study the dimensional behaviour of a plain knitted fabric made of cotton under cyclic elongations. First, a geometrical modeling of the knitted loop based on image processing was established. Then, an experimental fatigue apparatus permitting to obtain large number of axial periodical deformations was designed and constructed. This fatigue apparatus has been associated with the image processing device permitting then the measurement of fabric permanent deformations. This fatigue test that simulates the use of a knitted garment permitted to judge the fabric aptitude to recover its initial dimensions after cyclic elongations and to explain phenomena associated to this kind of constraints such as loop deformation, yarn elasticity and fibres slippage. These data present a great interest to fabric and clothing manufacturers who can do more judicious choices concerning yarn and knitted structure characteristics.

2. Material and methods

2.1 Geometric modelling of knitted loop

In the literature, the geometry of a plain knitted fabric loop was often described with simple theoretical models based on particular assumptions. That means that the loop shape was assumed to be composed of regular geometries such arcs of circle, segments or hexagons.

In our work, we tempted to model the stitch geometry using curves governed by special mathematical functions. In order to come closer to the real geometric configuration of the stitch, the parameters of the mathematical functions were obtained from image processing of really existing knitted loops.

The examination of plain knitted fabric by using an optical microscope with adequate enlargement showed that the stitch present a symmetry axis *D* (Fig. 1). First, modelling half a loop with a polynomial function of the third degree was tried, but preliminary testing showed that this assumption led to a modelled loop presenting an angular point at the head and at the foot when joining left and right half a loop together. Then we had the idea to model the three elements of half a loop separately. In order to avoid the angular point, the head and the foot of half a loop were modelled by using strophoidal functions:

$$F(x) = m\left(\frac{t - x}{t + x}\right)^{0,5} x \qquad (1)$$

The interest of this kind of function is that the mathematical analysis showed the presence of horizontal and vertical tangents at the points defined by the coordinates *(0.62t, 0.3mt)* and *(t, 0)* (Fig. 2). Two curves zones CF_1 and CF_2 described by two strophoidal functions F_1 and F_2 defined in the interval [$0.62t$, t] were used to model respectively the head and the foot of half a loop. CF_2 was straightened with $\pi/2$ rotation.

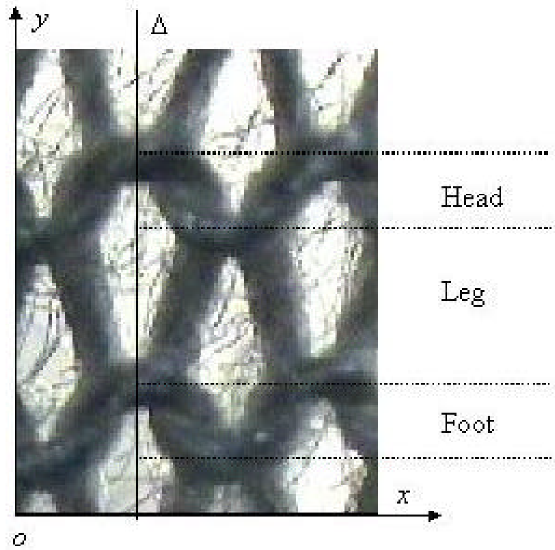

Figure 1. Plain knitted fabric observed with optical microscope

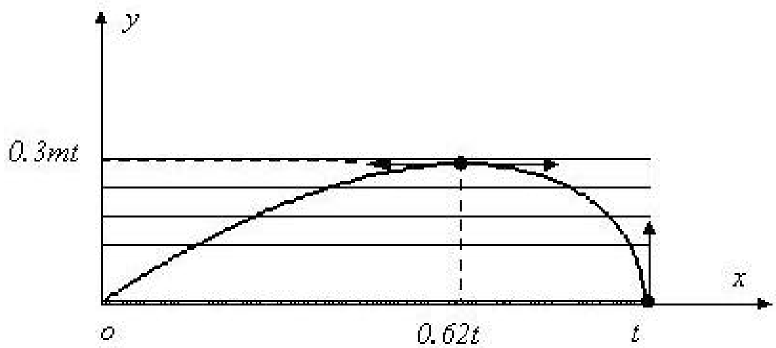

Figure 2. Strophoidal function

The loop leg was modelled by using the polynomial function:

$$P(x) = ax^3+bx \quad (2)$$

The analysis of this function showed the presence of two horizontal tangents at the points *A (-d, 0)* and *B (d, 0)*, where $d = \sqrt{\frac{-b}{3a}}$ (Fig. 3). After $\pi/2$ rotation, the curve zone described by the polynomial function defined in the interval [-*d*, *d*] can be used to model the leg of half a loop. Points *A* and *B* correspond to the contact points between adjacent loops in the same plain knitted fabric wale. The two curves zones corresponding to the head and the foot of half a loop are joined with the loop leg curve forming then half a loop (Fig. 4). The whole loop is then obtained by joining together two symmetrical half a loop (Fig. 5).

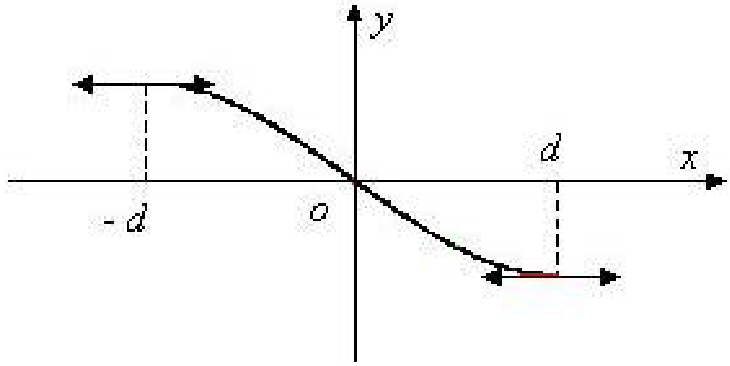

Figure 3. Polynomial function

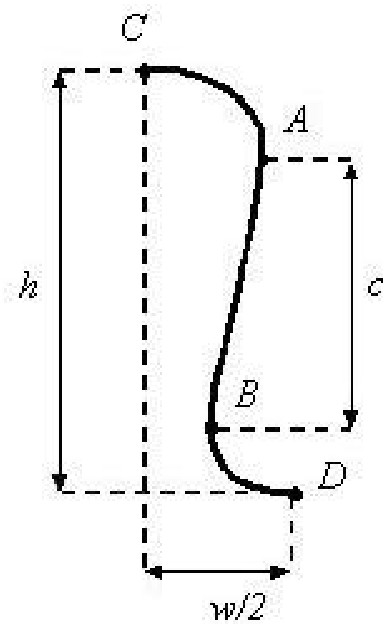

Figure 4. Half a loop elements

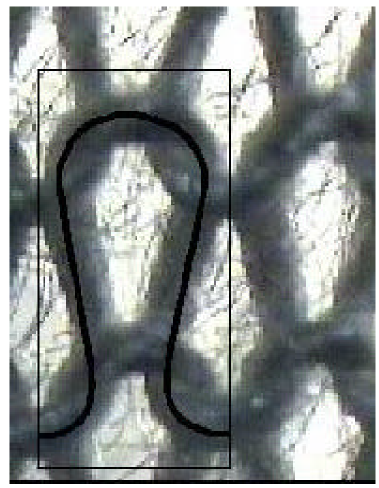

Figure 5. Modelled loop

The mathematical analysis of the strophoidal and the polynomial functions permitted to calculate the following loop dimensional parameters:

$$w = 2\left\{0.38(t_1 + t_2) - \tfrac{2}{3}bd\right\} \quad (3)$$

$$h = 0.3(m_1t_1 + m_2t_2) + 2d \quad (4)$$

$$c = 2d \quad (5)$$

$$l = 2\left(\frac{1}{0.38t_1} \bullet \int_{0.62t_1}^{t_1} F_1(x)dx + \frac{1}{0.38t_2} \bullet \int_{0.62t_2}^{t_2} F_2(x)dx + \frac{1}{2d} \bullet \int_{-d}^{d} P(x)dx\right) \quad (6)$$

Where w is the loop's width, h is the loop's height, c is the distance between two adjacent plain knitted fabric rows and l is the loop's length.

The aim of the image processing device was to be able to model the loop of a plain knitted fabric from a picture numerically acquired with an optical microscope. For this purpose a program was written with Microsoft Visual Basic 6.0 software. First, the loop was virtually localized with a rectangle, then four points corresponding to the contact points with adjacent loops (points *A* and *B*) and to the ends of half a loop (points *C* and *D*) were pointed with the computer mouse. The developed program extracts the coordinates of the four points and calculates the functions and the loop dimensional parameters as indicated above.

2.2. Experimental fatigue tester

In knitted structure load-deformation test, special clamps presenting two rolls should be used in order to avoid the sample destruction near grabbing zones. Fatigue test could last many hours, the knitted sample should be then correctly grabbed. For the purpose of this work two roll clamps for knitted fabrics were fabricated according the French standard NF G 07-140 (Fig. 6). Theses clamps normally used with traction dynamometer will be mounted on the fatigue tester.

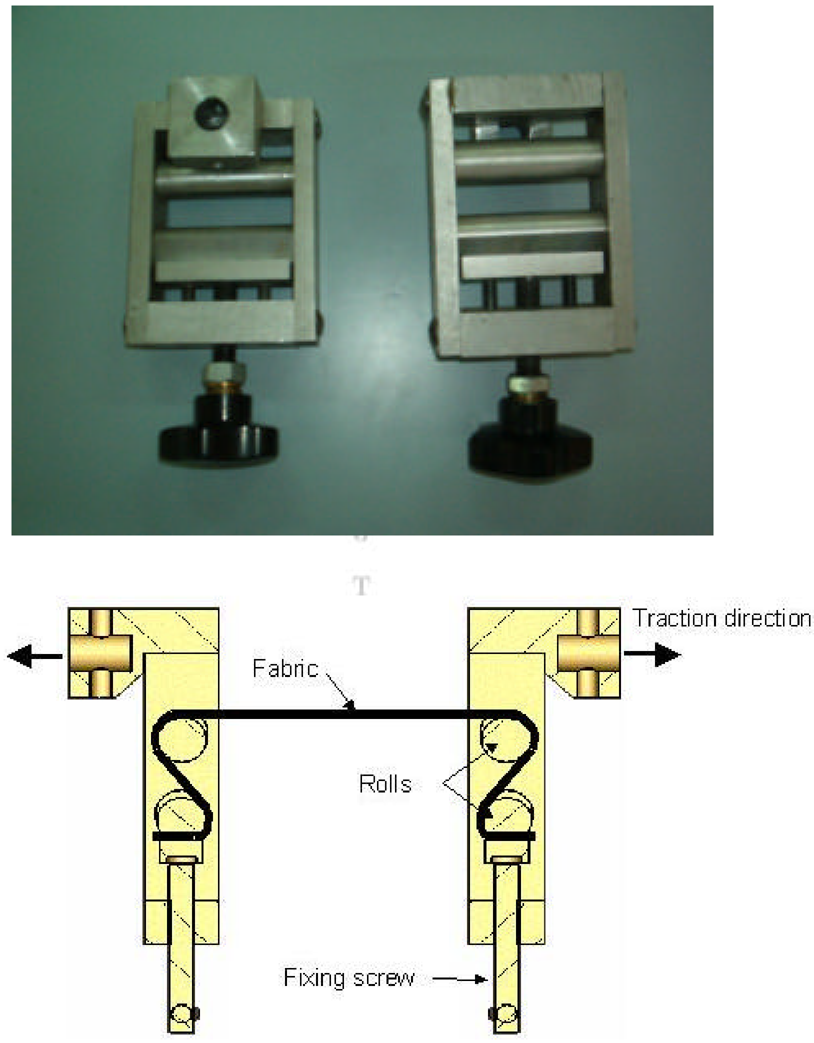

Figure 6. Roll clamps

The fatigue tester (Fig. 7) is essentially composed of a fixed clamp and a mobile clamp mounted on a carrier. The carrier is guided with two cylindrical guiding bars without friction by using two cylindrical ball bearings. The translation motion of the carrier is obtained with a connecting rod fixed on a rotating disk with a ball-andsocket joint. The rotating disk is fixed on an electrical motor shaft. The motor turns at 100 round/minute and generates a cyclic displacement of the mobile clamp with 40 mm amplitude.

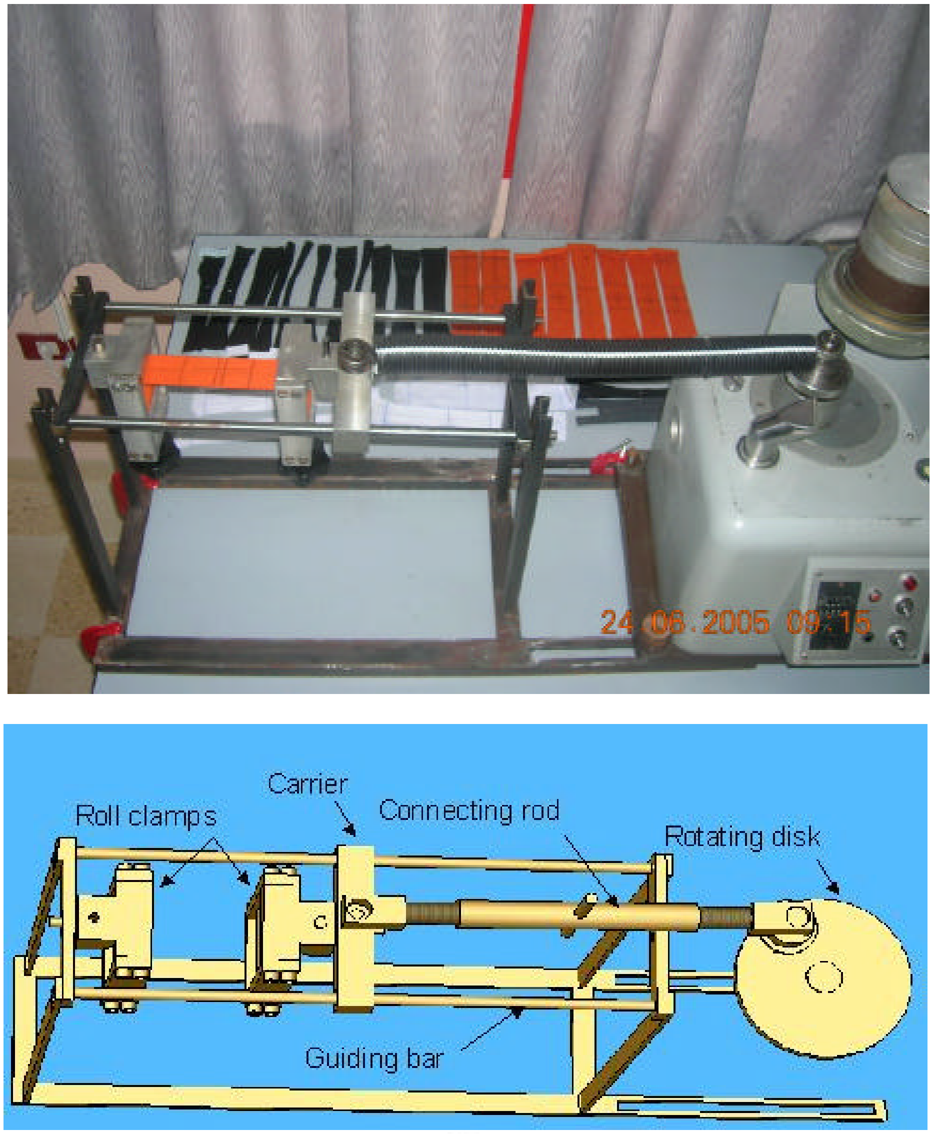

Figure 7. Fatigue tester

The tested sample is 200 mm long and 50 mm width. The initial distance between clamps is 100 mm (100 mm was used to grab the sample) according to the French standard NF G 07-140. We planned to test the fatigue of a plain knitted fabric with traction in the wale direction at four different numbers of cycles. The tested plain knitted fabric had the following features:

- Yarn: cotton, 40 tex
- Machine gauge: 26 needle/inch
- Row density: 13.18 row per cm
- Wale density: 11.07 wale per cm

After fatigue test, every sample was relaxed at rest on a flat surface. Row per cm and wale per cm were regularly measured during relaxation.

3. Results

Figure 8 and figure 9 show the evolution of row per cm and wale per cm during relaxation with the different fatigue test numbers of cycles. Each point in the figures is the mean of five measurements at different positions of the sample.

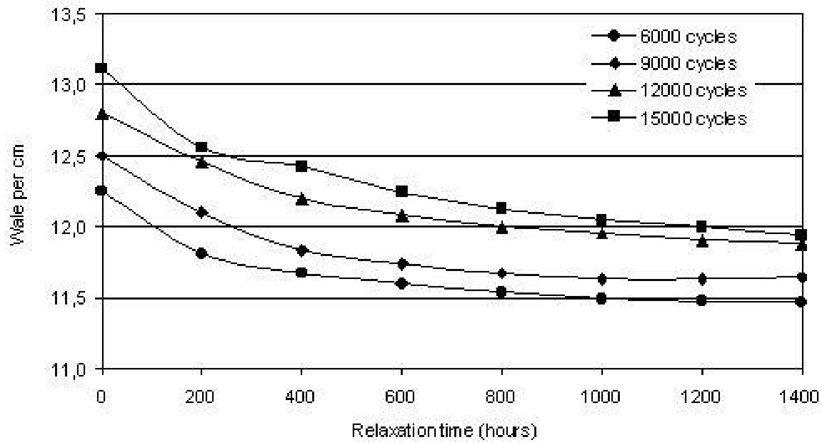

Figure 8. Evolution of wale per cm with relaxation time

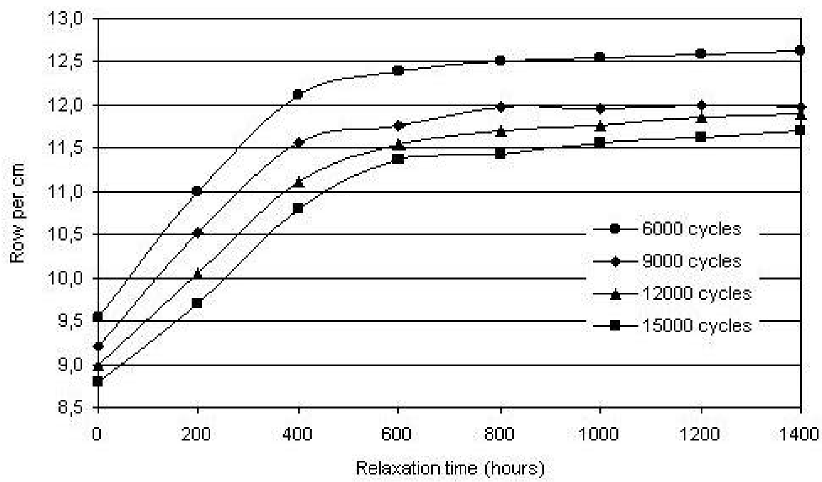

Figure 9. Evolution of row per cm with relaxation time

The repeated traction decreased row per cm and increased wale per cm and increasing the number of cycles further decreased row per cm and increased wale per cm. The fatigue test involved lengthening in the wale direction and shrinkage in the row direction. This deformation was preserved when fatigue test was stopped but decreased progressively with relaxation. Row per cm increased rapidly between 0 and 400 hours relaxation, then increased slowly in an asymptotic shape but never reaches value before fatigue test (13.18 row per cm). Similar observations were obtained with the decrease of wale per cm. Fatigue test involved a permanent biaxial deformation depending on the number of cycles.

In order to understand physical phenomena resulting from fatigue test, we compared the geometrical characteristics of the plain knitted fabric before and after 15000 cycles test.

	Before fatigue test	After fatigue test (15000 cycles)
w (cm)	0,090	0,080
h (cm)	0,116	0,132
l (cm)	0,368	0,419

Table I. Loop's dimensions before and after fatigue test

Table I summarizes the loop dimensions obtained from the image processing procedure described above. Each value of the table is the mean of five measurements at different positions of the sample. We can clearly see that loop's height increased and loop's width decreased similarly to the variation of row per cm and wale per cm previously observed. Simultaneously, the fatigue deformation involved an increase of loop's length of approximately 14%.

4. Discussion

Fatigue test is a dynamic test that simulates deformation applied on fabric during wearing. The application of this test on a plain knitted fabric made of cotton involved deformations that decrease with relaxation. After elongation, spun yarns do not recover initial dimensions instantaneously but progressively with time. The partial recovery of the knitted fabric dimensions during relaxation can be explained by the hysteresis phenomenon of spun yarns. This recovery can be incomplete depending on the initial elongation. In our case, the plain knitted fabric made of cotton undergone an important permanent deformation after fatigue test and relaxation. This deformation is about 12% lengthening in the wale direction and 6% shrinkage in the row direction after 1300 hours (approximately 2 months) relaxation with 15000 cycles fatigue test.

Similar observations have been formulated by Choi *et al.* [2] concerning dimension evolution of relaxed plain knitted fabric after knitting process. He explained, by using an energy approach, that internal energy in the yarn is maximum after it has been knitted into a fabric, but when the fabric is fully relaxed, the internal energy is at its minimum. During relaxation row per cm increased and wale per cm decreased due to internal energy variation. Similarly, Munden [11] led an experimental study showing that plain knitted fabric dimensions change during relaxation because of loop's length changes, but tend to reach a stable equilibrium state. Experimental observations by Doyle [5] confirmed the dependence of fabric dimensions on the loop's length of plain knitted fabrics.

Measurements of loop's height, width and length performed by image processing show that loop's deformation involved by cyclic traction corresponds to a variation of loop's height, loop's width and also loop's length. Immediately after fatigue test, friction between the loops temporarily maintains the loop shape, but that shape will changes progressively. At fully relaxed state, all frictional forces vanished since there is no more relative movement.

The permanent deformation obtained after fatigue test can be explained by plastic deformation due to fibre slippage and/or fibre permanent extension. Fibre slippage phenomenon depends on bending and torsion of the yarn, while fibre permanent extension depends on the fibre viscoelasticity. It would be very interesting to simulate fibres slippage in the knitted yarns in order to predict without experiments permanent deformations due to fabric fatigue, but there is no suitable yarn bending model in the literature. One major reason is that the complicated movement of fibres in the yarn during bending deformation can not be simulated satisfactorily. Once this problem is solved, plain knitted fabric fatigue could be predicted by starting with the fibre properties.

5. Conclusions

We have developed a new experimental device permitting to test dimensional behaviour of knitted fabric under large number of cyclic elongations. This dynamic tester simulates knitted fabric deformation during garment wearing. It was associated with an image processing device in order to measure fabric and loop deformation. The developed devices are practical tools that can be used by fabric and clothing manufacturers in order to evaluate long-term elasticity of the knitted fabric used in stretchable garments such as underwear and sportswear.

A new geometrical modelling of the knitted loop based on image processing of existing plain knitted fabrics was proposed. It suggests to model the different elements of a loop with strophoidal and polynomial functions. The fatigue test applied to a plain knitted fabric made of cotton involved a variation of fabric dimensions and a permanent deformation that persists after relaxation. This permanent deformation depends widely on the number of repetitive cycles. The analysis of the loop geometry with the image processing device permitted to conclude that deformation involved by fatigue test corresponds to a displacement and a lengthening of the yarn composing the loop.

Substantial theoretical study aiming to model fibre slippage in the yarn and fibre viscoelasticity is necessary in order to understand hysteresis phenomena of spun yarns and to predict plain knitted fabric dimensional behaviour from yarn and fibre properties.

References

[1] Araujo, M., Fangueiro, R. and Hong, H., Modelling and Simulation of the Mechanical Behaviour of Weft-Knitted Fabrics for Technical Applications, Part II: 3D Model Based on the Elastica Theory, *AUTEX Res. J.*, **4**, 26-32 (2003).

[2] Choi, K.F. and LO, T.Y.,. An Energy Model of Plain Knitted Fabric, *Text. Res. J*., **73**, 739-746 (2003).

[3] Demiroz, A., and Dias, T., A Study of the Graphical Representation of Plain-Knitted Structures, Part I: Stitch Model for Graphical Representation of Plain-Knitted Structures, *J. Text. Inst,* **91**, 463-480 (2000).

[4] Doyle, P.J., Some Fundamental Properties of Hosiery Yarns and their Relation to the Mechanical characteristics of Knitted Fabrics, *J. Text. Inst.*, **43**, 19-35 (1952).

[5] Doyle, P.J., Fundamental Aspects of the Design of Knitted Fabrics, *J. Text. Inst.,* **44**, 561-578 (1953).

[6] Hepworth, B., and Leaf, G.A.V., The Mechanics of an Idealised Weft-Knitted Structures, *J. Text. Inst.*, **67**, 241-248 (1976).

[7] Leaf, G.A.V. and Glaskin, A., The Geometry of the Plain Knitted Loop, *J. Text. Inst.*, **46**, 587-605(1955).

[8] Leaf, G.A.V., Models of the Plain Knitted Loop, *J. Text. Inst.*, **51**, 49-58 (1960).

[9] Leaf, G.A.V., The Stresses in the Plain Knitted Loop, *J. Text. Inst.*, **52**, 351-365 (1961).

[10] MacRory, B. M., McCraith, J. R., and McNamara, A. B., The Biaxial Load-Extension Properties of Plain Weft Knitted Fabrics: A Theoretical

Analysis, *Text. Res. J.*, **45**, 746-760 (1975).

[11] Munden, D.L., The Geometry and Dimensional Properties of Plain-Knit Fabrics, *J. Text. Inst.*, **50**, 448-471 (1959).

[12] Pierce, F.T., Geometrical Principles Applicable to the Design of Functional Fabric, *Text. Res. J.*, **17**, 123-147 (1947).

[13] Postle, R. and Munden, D. L., Analysis of the Dry Relaxed Knitted Loop Configuration, *J. Text. Inst.*, **58**, 329-365 (1967).

[14] Postle, R., Dimensional Stability of Plain Knitted Fabrics, *J. text. Inst.*, **59**, 65-77 (1968).

[15] Semnani, D., Latifi, M., Hmzeh, S. and Jeddi, A.A.A., A New Aspect of Geometrical and Physical Principles Applicable to the Estimation of Textile Structures: An Ideal Model for the Plain Knitted Loop, *J. Text. Inst.*, **94**, 203-211 (2003).