

# Non-linear Simulation of Drying of Plain Knitted Fabric using Mass-Spring-Damper Model and Genetic Algorithm Optimization

**V. Mozafary & P. Payvandy\***

Department of Textile Engineering,  
University of Yazd, Iran

E-mail: Mozafary@stu.yazd.ac.ir , peivandi@yazd.ac.ir

\*Corresponding author

**M. M. Jalili**

Department of Mechanical Engineering,  
University of Yazd, Iran

E-mail: Jalili@yazd.ac.ir

Received: 4 July 2014, Revised: 7 September 2014, Accepted: 12 October 2014

**Abstract:** In this study, the longitudinal shrinkage behavior of knitted fabrics during drying has been studied. In this context, a model is presented to predict the longitudinal shrinkage of plain knitted fabric during drying process. In order to model the shrinkage behavior, a 1DOF model consists of a mass, a linear spring and a linear damper have been used. In presented model the time-varying mass is considered due to fabric drying process. Nonlinear Equation of motion derived from the model have been solved using Three-order Straight Forward Expansion method. The results of the model were compared with the experimental results for five samples with different courses densities. The results shown that in high courses densities the presented model is capable enough to predict the longitudinal shrinkage of plain knitted fabric mass center during drying process. Error rate is 11.3% for the samples with high density. But with decrease in density, the error rate increases to 18%, where the genetic algorithm is used to optimize the model. Using optimized model the simulated error rate dropped to 5.7% for samples with high density while the rate dropped to 6.1% with decrease in density.

**Keywords:** Drying, Genetic Algorithm, Knitted Fabric, Simulation, Straight Forward Expansion

**Reference:** Mozafary, V., Payvandy, P., and Jalili, M. M., "Non-linear Simulation of Drying of Plain Knitted Fabric using Mass-Spring-Damper Model and Genetic Algorithm Optimization", Int J of Advanced Design and Manufacturing Technology, Vol. 7/ No. 4, 2014, pp. 67-76.

**Biographical notes:** **P. Payvandy** received his PhD in Textile Engineering from Amirkabir University, Iran in 2008. He is currently Assistant Professor at the Department of Textile Engineering, Yazd University, Yazd, Iran. His current research interest includes Physical modelling of Flexible Material and Meta-Heuristic Optimization. **M. M. Jalili** is Assistant Professor of Mechanical Engineering at the Yazd University, Iran. He received his PhD in Mechanical Engineering from Sharif University of Iran. His current research focuses on dynamic modelling of Multibody Systems. **V. Mozafary** is PhD Student in Textile Engineering at Yazd University, Yazd, Iran.

## 1 INTRODUCTION

Knitted fabrics are widely used by the apparel industry due to their good comfort, flexibility, elasticity, and formability properties. Nevertheless their dimensions are not stable due to the shrinkage of the various washing processes. Dimensional stability of knitted fabrics has always been considered by researchers. Won investigated the influence of machine gauge, loop length, Knitting tension, yarn twist, washing methods and drying on fabric shrinkage by measuring changes in loop geometry [1].

Knapton et al. studied dimensional stability of knitted fabric by mechanical and chemical relaxation methods. Their study also covered the influence of the cotton-fiber type on stable-fabric geometry [2]. Amir Bayat et al. by using the energy method, have analyzed the impact of the knitting machine settings, speed and tension settings on the sewing fabric shrinkage. They showed that temperature setting in the tumble dryer had no effect on shrinkage and the increased exposure to agitation that occurred in tumble-drying under a low temperature setting had no effect on shrinkage [3]. Higgins et al. reported the effect of washing time, temperature setting, and moisture content on fabric shrinkage. Their study found that maximum drying occurred in the first cycle of drying shrinkage. They also showed that temperature does not have a significant effect on shrinkage [4].

Onal et al. investigated the influence of material type, percentage of mixed fiber and thickness on fabric shrinkage, where they found that those properties have a significant effect on shrinkage. Also the thickness of fabric is directly proportional to width shrinkage and varies inversely with the length shrinkage [5]. Chen et al. studied the effects of loop length, yarn linear density, cover factor, yarn twist and fiber diameter on the shrinkage of plain knit woolen fabric using regression analysis. The result of the multiple regression analysis indicated that the major factors affecting felting properties are cover factor and loop length. Furthermore, fiber diameter and yarn twist also have a significant effect on shrinkage [6].

Ucar et al. studied the effect of several fabric parameters such as pile type, fiber type, fabric thickness and kind of relaxation on some physical properties of piled knitted fabric such as dimensional changes (shrinkage), drapability and abrasion [7]. Sze Lo et al. studied the effect of resin finish on dimensional changes of knitted fabric. Furthermore, they analyzed relationship between the degree of set and dimensional stability and showed that the degree of set increases with increase in resin level [8]. Souza et al. predicted dimensional changes of knitted fabric considering tissue type, yarn grade, loop length, loop shape factor and machine gauge [9]. Rebecca et al.

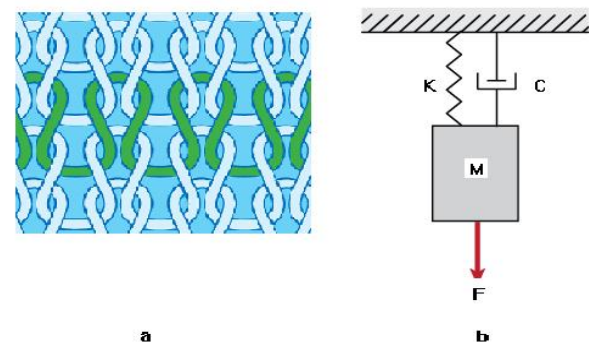
investigated influence of six cycles of washing and temperature on knitted fabric properties including dimensional changes and tightness [10].

In general, knitted fabric encounters dimensional loss (shrinkage); in fact they tend to achieve stable and sustainable conditions. These changes may lead to a jamming structure. A large number of factors are responsible for causing these changes in knitted structures; these are all associated with the yarn, knitting, finishing and making-up of the fabrics. The major reason of shrinkage is yarn tension during feeding and picking up. Another problem that manufacturers have to contend with is the factors affecting variability in customer washing processes. Fibers will swell due to moisture absorption and so their diameter increase. Therefore, fabric yarns become close to each other and the fabric dimensions reduces [11].

In previous research, a model was presented to predict the plain knitted fabric length changes during the drying process that the only applied force on the fabric was its weight [12]. In the continuation of previous work, the major aim of this research is the optimization of the presented model using genetic algorithm. Considering that transverse changes compared to longitudinal changes. The model presented in this research is able to predict length changes in wet knitted fabrics with various density and moisture percent by passing time which is the innovation of this study. It is important to consider that clothes become wet through sweating or external sources like the rain.

## 2 MODELING

In this study, in order to simulate the shrinkage behavior and dimensional changes of knitted fabric during drying under its own weight, a mass-spring-damper model was used. The presented model is illustrated in Fig. 1.



**Fig. 1** (a) Structure of plain knitted fabric, (b) The proposed model for predicting length changes of fabric

**Assumptions**

Some of the following assumptions have been made to simplify the analysis:

- a) Spring and damper are assumed to be linear.
- b) Mass is assumed to be concentrated.
- c) Flow rate of outlet water is considered constant during drying process.

**Model Analysis**

According to Fig. 1.b, the Equation of motion of plain knitted fabric can be presented as:

$$M\ddot{X} + C\dot{X} + KX = Mg \tag{1}$$

Where  $M$  is mass of the fabric and its fluid,  $X$  is length change,  $\dot{X}$  is velocity,  $\ddot{X}$  is acceleration and  $C$  and  $K$  is damping and stiffness coefficient of fabric respectively. Initially fabric is wet. Over time it loses moisture, therefore the mass varies with time. Total fabric mass can be represented as follows:

$$M = m - \tilde{m}(t) \tag{2}$$

Where  $m$  is the wet fabric mass and  $\tilde{m}(t)$  is the mass of outlet water over time which is defined as below:

$$\tilde{m}(t) = a \times t \tag{3}$$

Where  $a$  is flow rate of outlet water. By introducing two new variables, the fabric initial static equilibrium position  $\bar{x}$  and the fabric center of mass position  $x$ , it can be written as:

$$\bar{x} + x = X \tag{4}$$

Where:

$$k \bar{x} = mg \tag{5}$$

Eq. (1) can be obtained by substituting Eq. (4) into Eq. (1) and dividing the two sides to  $m$ :

$$\left(1 - \frac{a}{m}t\right)\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}(x + \bar{x}) = 1 - \frac{a}{m}tg \tag{6}$$

Eq. (7) can be obtained by substituting Eq. (5) into Eq. (6):

$$\left(1 - \frac{a}{m}t\right)\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = -\frac{a}{m}tg \tag{7}$$

For simplification, parameters  $\alpha, \gamma, \zeta$  are introduced as follows:

$$\alpha = \frac{a}{m} \tag{8}$$

$$\gamma = \frac{c}{m}g \tag{9}$$

$$\zeta = \frac{c}{c_0} \tag{10}$$

Where  $C_0$  is Critical damping. Eq. (7) can be written as:

$$(1 - \alpha t)\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2x = -\gamma t \tag{11}$$

Where:

$$\omega_n^2 = \frac{K}{m} \tag{12}$$

Where  $\omega_n$  is natural frequency of the linear system. Straight Forward Expansion method is used to solve Eq. (11) [13]. To solve Eq. (11), new parameters  $\beta$  and  $\gamma$  are defined as follows:

$$\beta = \frac{\alpha}{\varepsilon^2} \tag{13}$$

$$\lambda = \frac{\gamma}{\varepsilon^2} \tag{14}$$

Eq. (15) can be obtained by substituting Eqs. (13) and (14) into Eq. (11):

$$(1 - \varepsilon^2\beta t)\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2x = -\lambda\varepsilon^2t \tag{15}$$

Where  $\varepsilon$  is perturbation parameter. The solution of Eq. (6) is assumed in the form of an infinite series of the perturbation parameter  $\varepsilon$  which is as follows:

$$x(t) = \varepsilon x_1(t) + \varepsilon^2 x_2(t) + \varepsilon^3 x_3(t) + \dots \tag{16}$$

In this study, the third-order perturbation method is used to solve the differential Equation. Therefore the vibration response is considered as follows:

$$x(t) = \varepsilon x_1(t) + \varepsilon^2 x_2(t) + \varepsilon^3 x_3(t) \tag{17}$$

Eq. (18) can be obtained by substituting Eq. (17) into Eq. (15):

$$\begin{aligned} &(1 - \varepsilon^2\beta t)(\varepsilon\ddot{x}_1 + \varepsilon^2\ddot{x}_2 + \varepsilon^3\ddot{x}_3) + 2\zeta\omega_n(\varepsilon\dot{x}_1 + \varepsilon^2\dot{x}_2 + \varepsilon^3\dot{x}_3) \\ &+ \omega_n^2(\varepsilon x_1 + \varepsilon^2 x_2 + \varepsilon^3 x_3) = -\lambda\varepsilon^2t \end{aligned} \tag{18}$$

Since the perturbation parameter  $\varepsilon$  could have been chosen arbitrarily, the coefficients of the various powers of  $\varepsilon$  must be equated to zero. This leads to a system of Equations which can be solved successively:

$$\varepsilon^1 : \dot{x}_1 + 2\zeta\omega_n\dot{x}_1 + \omega_n^2x_1 = 0 \tag{19}$$

$$\varepsilon^2 : \ddot{x}_2 + 2\zeta\omega_n\dot{x}_2 + \omega_n^2x_2 = -\lambda t \tag{20}$$

$$\varepsilon^3 : \ddot{x}_3 + 2\zeta\omega_n\dot{x}_3 + \omega_n^2x_3 = +\beta t\dot{x}_1 \tag{21}$$

To solve Eq. (19),  $x_1$  is considered as follows:

$$x_1 = C e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) \tag{22}$$

Where  $\omega_d$  is damping frequency of system that is  $\omega_d = \omega_n(1 - \zeta^2)^{1/2}$ . Solution of Eq. (20) can be represented as:

$$x_2 = -\frac{\lambda}{\omega_n^2} \left( t - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \right) \quad (23)$$

Eq. (24) can be obtained by substituting Eq. (22) into Eq. (21):

$$x_3 = -C \zeta \omega_n \beta t^2 e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \quad (24)$$

The response of the system may be found by substituting Eqs. (22) to (24) into Eq. (17):

$$x = \varepsilon C e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) - \frac{\lambda \varepsilon^2}{\omega_n^2} \left( t - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \right) - C \varepsilon^3 \zeta \omega_n \beta t^2 e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \quad (25)$$

Eq. (26) can be obtained by considering  $\varepsilon C = A$ :

$$x = A e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) - \frac{\lambda}{\omega_n^2} \left( t - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \right) - A \alpha \zeta \omega_n \beta t^2 e^{-\zeta\omega_n t} \sin(\omega_d t + \varphi_0) \quad (26)$$

Imposing the initial conditions  $x_0(t) = 0$ ,  $\dot{x}_0(t) = 0$  into Eq. (26), the constants of  $A$  and  $\varphi$  can be obtained as:

$$A = -\frac{\dot{\gamma}}{\omega_n^2 \sqrt{1-\zeta^2}}, \varphi_0 = 0 \quad (27)$$

After drying the sample, there are no changes in the mass. In this case Eq. (1) can be written as follow:

$$\ddot{x} + 2\zeta\omega_n \dot{x} + \omega_n^2 x = 0 \quad (28)$$

The solution of Eq. (28) can be represented as follow:

$$x = A e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) \quad (29)$$

Constant of Eq. (29) can be obtained by substituting position and velocity conditions after drying. Eqs. (26) and (29) show length changes of fabric with respect to time. By using this model, shrinkage behavior of knitted fabric can be predicted.

### Model analysis with textile behavior

Viscoelasticity describes time-dependent mechanical properties. Soft tissues consist of both solid and fluid, and behave as viscoelastic material. The mechanical properties are strain-rate-dependent. Skin tissues show stress relaxation under constant strain and creep under constant stress. With increasing strain rate, the material becomes softer, therefore, it is necessary to monitor and report the strain rate.

The stress gradually decreases with time when the fabric is stretched under a constant strain rate and then kept constant, where this phenomenon is called stress relaxation. Alternatively, when the tissue is stretched to a certain stress level and then kept constant, its strain increases with time. This phenomenon is called creep. Soft tissues also illustrate considerable hysteresis under a cyclic load, i.e. the stress-strain curve shows two distinct paths during the loading and unloading cycle (Fig. 2). Because of its viscoelastic behavior, stress-strain response at any given moment depends not only on time but also depends on the deformation [14].

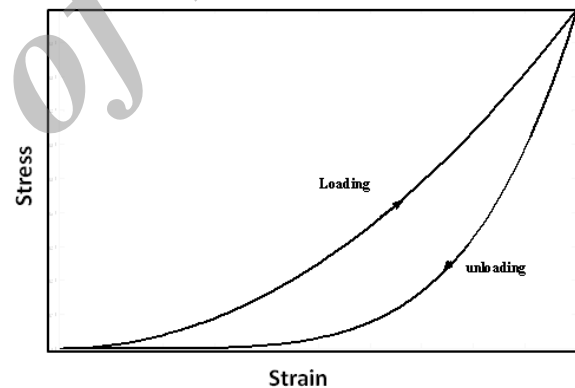


Fig. 2 Stress-strain curve of fabric (hysteresis).

The viscoelasticity of a tissue is often modeled by using models composed of ideal springs for the elasticity and ideal dashpots for the viscosity. Thus this model is suitable for modeling the behavior of viscoelastic textile due to its ideal elasticity and viscosity coefficient. As mentioned before, with increasing strain rate, the material becomes softer i.e. for a constant force, the elongation is more. This property is equivalent to spring stiffness coefficient in the developed model. Comparison between changes of spring stiffness coefficient and its impact on the system response are illustrated in Fig. 3. As observed in Fig. 3 by reducing the spring stiffness, the amount of elongation is increased. Very slow oscillation is observed in the first milliseconds that are due to elasticity properties of tissue; because of high damper coefficient, this oscillation is damped quickly.

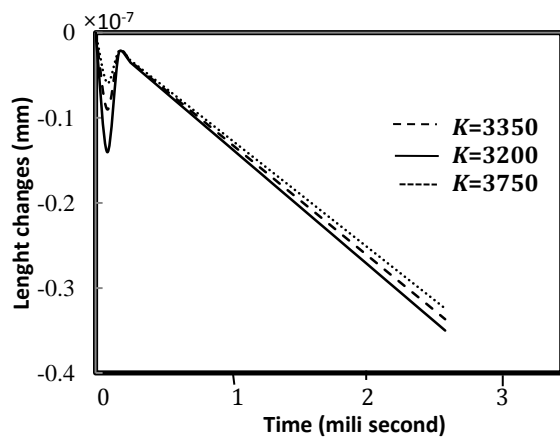


Fig. 3 Effect of spring stiffness on system response.

### 3 EXPERIMENTAL

Fabrics specimens (100% acrylic (8/2 Ne), 60×60 cm<sup>2</sup>) were produced with a circular knitting machine (gauge no. 15). The specifications of 5 samples are illustrated in Table 1. Before taking any measurements, all fabrics were placed on a flat surface for 24 hours in standard atmospheric conditions of 20 ± 2°C and 65 ± 2% RH (dry relaxed fabrics).

Table 1 Specifications of samples

| N o | Material | Weight (gram) | Weave | Yarn count (Ne) | Wale density (Cm <sup>-1</sup> ) | Course density (Cm <sup>-1</sup> ) |
|-----|----------|---------------|-------|-----------------|----------------------------------|------------------------------------|
| 1   | Acrylic  | 145           | Plain | 16/2            | 6.7                              | 14.7                               |
| 2   | Acrylic  | 137           | Plain | 16/2            | 6.7                              | 14.3                               |
| 3   | Acrylic  | 129           | Plain | 16/2            | 6.7                              | 13.9                               |
| 4   | Acrylic  | 121           | Plain | 16/2            | 6.7                              | 13.5                               |
| 5   | Acrylic  | 113           | Plain | 16/2            | 6.7                              | 13.1                               |

After relaxation, wale and course density were determined based on the Standard [15]. All specimens were then subjected to the relaxation treatment in a standard washing machine at 60°C for 24 hours. After the washing and dry relaxation treatment, lengths changes during the time were recorded.

#### Measurement of length changes in samples during drying process

Wet samples were weighed and hung under its weight in standard atmospheric conditions. Sample length decreased as fabrics were drying until the moisture content disappeared. Longitudinal changes were recorded every 30 minutes. Three measurements were taken on each sample and their averages were recorded, and the results of experiments are tabulated in Table 2.

Table 2 Lengths and weights changes averages

| N0 | Time (minute) | Mass changes (different between wet and dry samples) (gram) | Length changes (different between wet and dry samples) (mm) |
|----|---------------|---|---|
| 1  | 0             | 502   | 10  |
|    | 30            | 403   | 8   |
|    | 60            | 328   | 6   |
|    | 90            | 246   | 4   |
|    | 120           | 174   | 3   |
|    | 150           | 98  | 1   |
| 2  | 0             | 533   | 13  |
|    | 30            | 423   | 10  |
|    | 60            | 341   | 7   |
|    | 90            | 267   | 4   |
|    | 120           | 186   | 3   |
|    | 150           | 118   | 2   |
| 3  | 0             | 577   | 15  |
|    | 30            | 454   | 11  |
|    | 60            | 361   | 7   |
|    | 90            | 282   | 5   |
|    | 120           | 196   | 4   |
|    | 150           | 101   | 3   |
| 4  | 0             | 584   | 18  |
|    | 30            | 463   | 13  |
|    | 60            | 352   | 9   |
|    | 90            | 246   | 7   |
|    | 120           | 178   | 6   |
|    | 150           | 109   | 3   |
| 5  | 0             | 603   | 20  |
|    | 30            | 484   | 14  |
|    | 60            | 391   | 10  |
|    | 90            | 286   | 7   |
|    | 120           | 212   | 6   |
|    | 150           | 123   | 4   |
|    | 180           | 13  | 1.2   |

The diagram of changes average of 5 samples weights over time are illustrated in Fig. 4, where Fig. 5 shows diagram of changes average of 5 samples lengths over time. As it is observed, changes in the length and weight of the sample increases initially and then decreases by reducing moisture content.

#### Measurement of initial modulus and Viscosity coefficient

Load-extension curve of samples were used to determine initial modulus and viscosity coefficient. Hence, strength experiments of samples were tested on a CRE Tensile testing machine according to ASTM Standard [16]. Samples lengths were set at 100 mm, samples widths at 50 mm and the extension rate was adjusted at 100 mm/minute. Five measurements were taken on each sample and their averages were recorded.

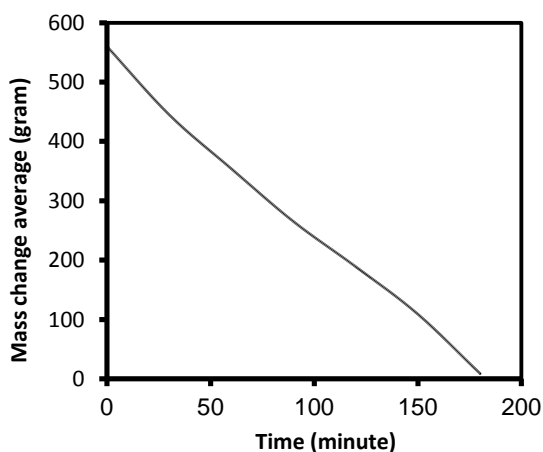


Fig. 4 Mass changes averages over time

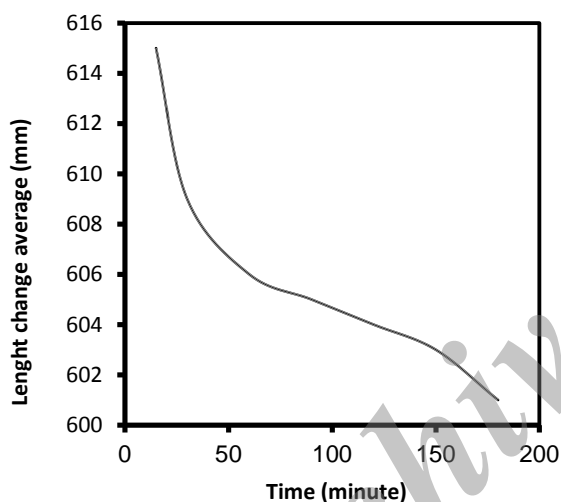


Fig. 5 Length changes averages over time

Samples were subjected to loading and unloading cycles where hysteresis diagram of sample 1 is illustrated in Fig. 8. In this diagram fabric is stretched on path A to B. Then in unloading path (B<sub>1</sub> to A<sub>1</sub>) by removing force, Sample length reduces but because of viscoelastic behavior there is hysteresis (A to A<sub>1</sub>), while in the next cycles, hysteresis effect reduces. Parameters *K* and *C* for each sample were estimated by fitting Eq. (30) and curves hysteresis of samples. For each sample, curves hysteresis are determined 5 times and average of 5 calculated values of *K* and *C* (which is determined from the hysteresis cycle diagram) was considered as model initial values. Results show that the spring force change against length change is linear, so parameter *K* may be assumed linear.

$$C\dot{x} + Kx = F \quad (30)$$

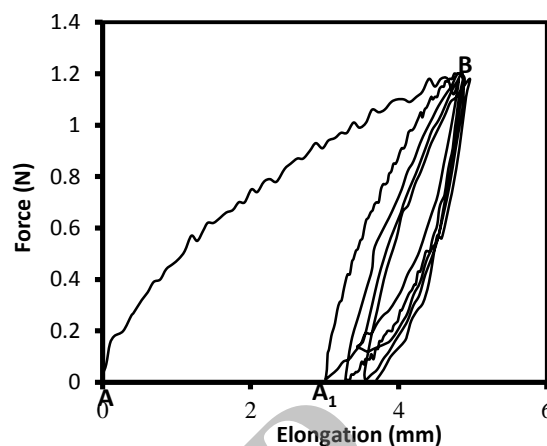


Fig. 6 Hysteresis curve of sample 1

#### 4 OPTIMIZATION EQUATION OF FABRIC LENGTH CHANGES BY USING GENETIC ALGORITHMS

Genetic algorithm was used to optimize motion equation and reduce the error between the experimental results and the predicted results (linearity assumption of mass changes over time). A genetic algorithm is an algorithm used to find approximate solutions to difficult problems through application of the principles of evolutionary biology to computer science. Genetic algorithms use biologically-derived techniques such as inheritance, mutation, natural selection, and recombination. Genetic algorithms are particular class of evolutionary algorithms. Fig. 7 shows the flowchart of a typical genetic algorithm. Genetic algorithms were first introduced by John Holland in the 1960s [17], where some related elements are defined as below.

**Encoding:** Encoding is a process of converting solutions in physical space to usable solutions in genetic algorithm.

**Initial population:** Generation of an initial population is the first step. Each solution is represented by a chromosome that is converted to a code by considering type of problem. Population sizing has been one of the important topics to consider in evolutionary computation. The initial population should be enough to allow the displacement operations by genetic algorithms in general search spaces. A large population size could make the algorithm expend more computation time in finding a solution [17].

**Parent selection:** In the selection phase, a pair of chromosomes is chosen to be combined; selection operator is the interface between the two generations and transfers some members of the current generation to the next generation. After selection, genetic operators are applied on the selected members. Values

conformity is criteria for selection of members. In the selection process, selection chance of each chromosome is proportional to its fitness, and controls the selection pressure, which in turn determines how fast the algorithms coverage. In this study, Roulette Wheel selection method is applied [18].

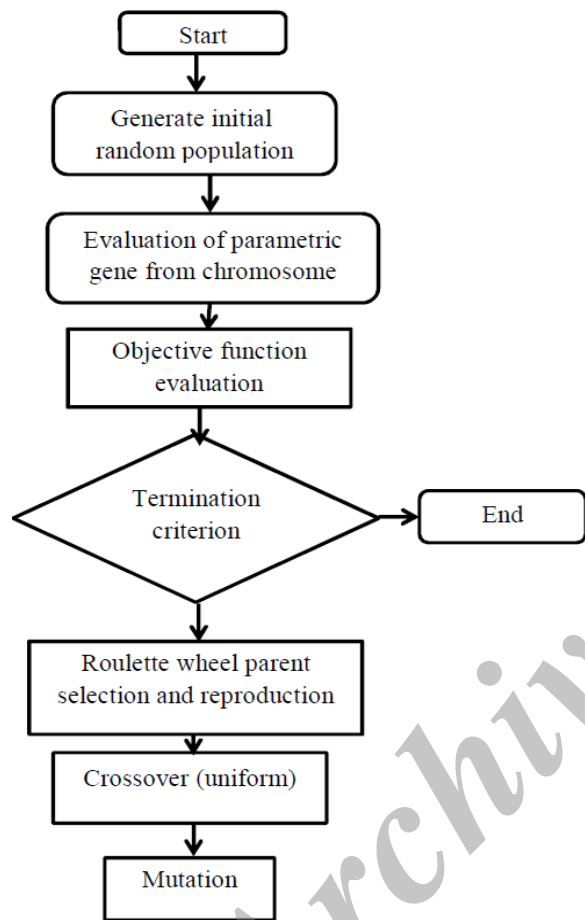


Fig. 7 Flow-chart of a Genetic algorithm [17].

**Crossover:** The crossover is a method for sharing information between chromosomes; it combines the features of two parent chromosomes to form two offspring, with the possibility that good chromosomes may generate better ones. Crossover types are: single-point crossover, two-point crossover and uniform crossover that uniform crossover is used in this study [18].

**Mutation:** The mutation operator arbitrarily alters one or more components, genes, of a selected chromosome so prevent falling into local optimization although variability of the population is remained. Mutation types are: swap mutation, reversion mutation and insertion mutation [18].

**Objective function:** Objective function determined selection chance and existence of a solution proportional to its fitness value. Objective function is both ascending and descending. Hypothesis of mass linear momentum over time, was one of the assumptions intended in the model. If second-order non-linear equation is considered for mass changes, Eq. (23) can be written as follow:

$$x_2' = -\frac{\lambda}{\omega_n^2} \left( (Dt^2 + Et + F) - \frac{1}{\sqrt{1-\zeta^2}} \times e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) \right) \quad (31)$$

Where parameters  $F$ ,  $E$  and  $D$  are non-linear coefficients of equation of mass changes during time. Model response can be obtained by substituting Eq. (31) into Eq. (17):

$$x = A e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) - \frac{\lambda}{\omega_n^2} \left( (Dt^2 + Et + F) - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) \right) - A \alpha \zeta \omega_n \beta t^2 e^{-\zeta\omega_n t} \sin(\omega_d t + \phi_0) \quad (32)$$

Genetic algorithm was used to decrease error between Eq. (32) and experimental data. So cost function is defined as follows:

$$R = \sum_1^n [X(n) - \bar{X}(n)] \quad (33)$$

Where  $n$  is the number of tests (equal 7),  $X(n)$  is experimental data of length changes,  $\bar{X}(n)$  is model dynamic response of length changes (Eq. (32)). In order to minimize Eq. (33), genetic algorithm was used to find the best answer for the three parameters  $D$ ,  $E$  and  $F$ . Matlab-R2011a software was employed to write the network codes and perform the final execution. Table 3 shows optimization variables limits and changes accuracy. Genetic algorithm parameters are shown in Table 4. After 50 runs of the algorithm, in order to minimize function cost, the best value for parameters  $D$ ,  $E$  and  $F$  are determined as shown in Table 5.

Fig. 8 illustrates variation of objective function for different number of generations during optimization. The results of this figure show clearly the convergence of optimization. By increasing the number of generations, the mean value of objective function shows decreasing behaviour which approaches gradually to the best value.

**Table 3** Optimization variables limits and changes accuracy

| Parameter        | D    | E    | F    |
|------------------|------|------|------|
| Lower limit      | -10  | -10  | -10  |
| Upper limit      | +10  | +10  | +10  |
| Changes accuracy | 0.01 | 0.01 | 0.01 |

**Table 4** Genetic algorithm parameters

| Parameter              | Value/Property           |
|------------------------|--------------------------|
| Population size        | 2000                     |
| Number of generations  | 30                       |
| Crossover percent      | 0.8                      |
| Mutation percent       | 0.3                      |
| Selection of parents   | Roulette Wheel Selection |
| Selection of crossover | Uniform                  |

**Table 5** Optimal value

| Parameter     | D                     | E    | F                     |
|---------------|-----------------------|------|-----------------------|
| Optimal value | $-4.5 \times 10^{-5}$ | 1.32 | $6.88 \times 10^{-4}$ |

As shown in Table 5 the calculated optimal values of D and F are extremely small (nearly zero). So optimizing equation of motion is as follows:

$$x = A e^{-\zeta \omega_n t} \sin(\omega_d t + \varphi_0) - \frac{\lambda}{\omega_n^2} ((1.32t) - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta \omega_n t} \sin(\omega_d t + \varphi_0)) - A \alpha \zeta \omega_n \beta t^2 e^{-\zeta \omega_n t} \sin(\omega_d t + \varphi_0) \tag{34}$$

**Table 6** Model parameters

| Spring stiffness (N/m <sup>2</sup> ) | Damper (N.s/m) | Initial mass (gram) | Mass changes stiffness | Optimal value (for optimized model) |      |
|--------------------------------------|----------------|---------------------|------------------------|-------------------------------------|------|
| K                                    | C              | m                   | a                      | E                                   |      |
| 1                                    | 4190           | 29                  | 0.647                  | 0.00044                             | 1.32 |
| 2                                    | 3420           | 28                  | 0.670                  | 0.00046                             | 1.32 |
| 3                                    | 2880           | 27                  | 0.714                  | 0.0005                              | 1.32 |
| 4                                    | 2576           | 25                  | 0.710                  | 0.00051                             | 1.32 |
| 5                                    | 3278           | 23                  | 0.716                  | 0.00052                             | 1.32 |

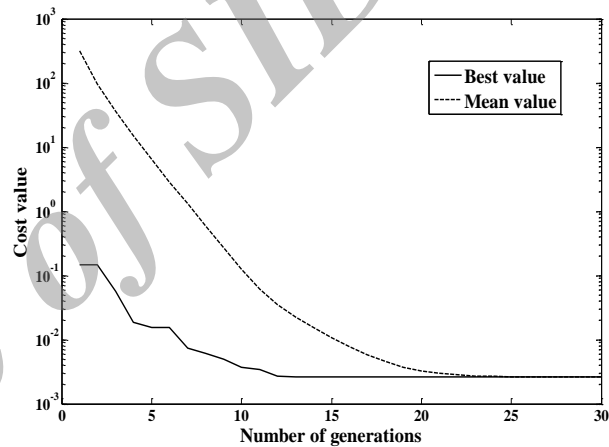
**5 RESULT AND DISCUSSION**

Parameters *K* and *C* were determined by using hysteresis curve (Fig. 8 and Eq. (31)), then responses of system are plotted for the samples. Table 6 shows initial models parameters and optimized model by using genetic algorithm parameters. Fig. 9 illustrates

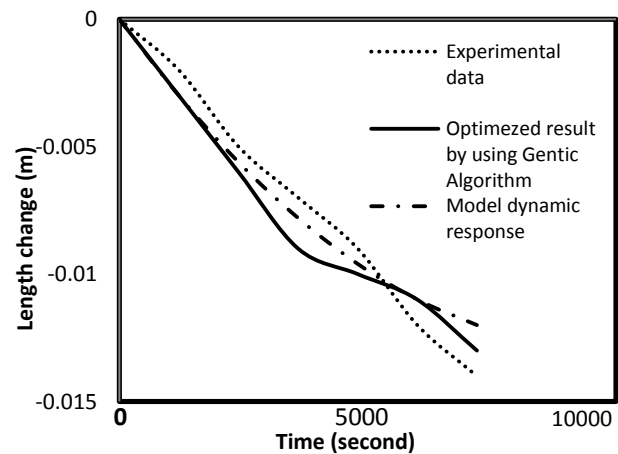
comparison between model dynamic response and optimized results (by using genetic algorithm) with experiments data of sample 2.

Length and mass changes were recorded seven times (0, 30, 60, 90, 120, 150 and 180 minutes). Results of model for predicting and optimized results by using genetic algorithm and errors are shown in Table 5. Errors may be due to the following reasons:

- 1) By considering fabric as concentrated mass, changes of mass center of fabric were recorded as length changes. Changes are not consistent throughout the fabric, while length changes are more on the cloth's hanging.
- 2) Spring and damper were assumed linear.



**Fig. 8** Variation of the best and mean values of cost function



**Fig. 9** Comparison between the model time response and optimized results by using genetic algorithm with experiments data (Sample 2)



**Table 7** Results of model for predicting and optimized results by using genetic algorithm and errors

| No                   | Time (minute) | Results of model | Experimental results | Optimized results by using genetic algorithm | Error percent (between model and experimental) | Error percent (between experimental and optimized result by using genetic algorithm) |
|----------------------|---------------|------------------|----------------------|--|--|--|
| 1                    | 30            | -0.00189         | -0.002               | -0.0021                                      | 5.5%   | 5.5%   |
|                      | 60            | -0.00484         | -0.0049              | -0.005                                       | 2%   | 1.2%   |
|                      | 90            | -0.00567         | -0.006               | -0.0061                                      | 5.5%   | 1.6%   |
|                      | 120           | -0.00760         | -0.007               | -0.0075                                      | 8%   | 7.1%   |
|                      | 150           | -0.00947         | -0.009               | -0.0086                                      | 5%   | 4.4%   |
|                      | 180           | -0.01134         | -0.01                | -0.0094                                      | 13.4%  | 6%   |
| <b>Error average</b> |               |                  |                      |  | <b>6.5%</b>                                    | <b>4.3%</b>  |
| 2                    | 30            | -0.00266         | -0.0030              | -0.003                                       | 11%  | 0%   |
|                      | 60            | -0.00508         | -0.0060              | -0.0056                                      | 15.3%  | 6%   |
|                      | 90            | -0.00730         | -0.0090              | -0.0078                                      | 19%  | 13.3%  |
|                      | 120           | -0.00969         | -0.0100              | -0.0096                                      | 3.1%   | 4%   |
|                      | 150           | -0.01210         | -0.0110              | -0.0110                                      | 10%  | 0%   |
|                      | 180           | -0.01453         | -0.0130              | -0.0120                                      | 11.7%  | 7.6%   |
| <b>Error average</b> |               |                  |                      |  | <b>12%</b>                                     | <b>5.1%</b>  |
| 3                    | 30            | -0.00328         | -0.0040              | -0.0039                                      | 18%  | 2.5%   |
|                      | 60            | -0.00625         | -0.0080              | -0.0072                                      | 21.8%  | 10%  |
|                      | 90            | -0.00938         | -0.0100              | -0.0101                                      | 6.2%   | 1%   |
|                      | 120           | -0.01250         | -0.0110              | -0.0124                                      | 13.6%  | 12.7%  |
|                      | 150           | -0.01550         | -0.0130              | -0.142                                       | 15% 15.2%                                      | 9.2%   |
|                      | 180           | -0.01728         | -0.0150              | -0.0155                                      |  | 3.3%   |
| <b>Error average</b> |               |                  |                      |  | <b>15%</b>                                     | <b>6.4%</b>  |
| 4                    | 30            | -0.00362         | -0.0050              | -0.0045                                      | 27.7%  | 10%  |
|                      | 60            | -0.00722         | -0.0090              | -0.0084                                      | 19.7%  | 6.6%   |
|                      | 90            | -0.01084         | -0.0110              | -0.0116                                      | 1.46%  | 5.4%   |
|                      | 120           | -0.01445         | -0.0120              | -0.0143                                      | 20.4%  | 19.2%  |
|                      | 150           | -0.01807         | -0.0160              | -0.0164                                      | 12.9%  | 2.5%   |
|                      | 180           | -0.02168         | -0.0180              | -0.0179                                      | 20.4%  | 0.5%   |
| <b>Error average</b> |               |                  |                      |  | <b>17%</b>                                     | <b>7.3%</b>  |
| 5                    | 30            | -0.00398         | -0.0060              | -0.0490                                      | 33.4%  | 7.1%   |
|                      | 60            | -0.00719         | -0.0100              | -0.0920                                      | 28.1%  | 8.2%   |
|                      | 90            | -0.01199         | -0.0130              | -0.0129                                      | 7.8%   | 0.7%   |
|                      | 120           | -0.01598         | -0.0140              | -0.0158                                      | 14.1%  | 12.8%  |
|                      | 150           | -0.01997         | -0.0180              | -0.0181                                      | 10.9%  | 0.5%   |
|                      | 180           | -0.02396         | -0.0200              | -0.0198                                      | 19.8%  | 1%   |
| <b>Error average</b> |               |                  |                      |  | <b>19%</b>                                     | <b>5%</b>  |

It is observed from Table 7 that error rate has been reduced about 5.9 percent by using genetic algorithm. There is also a greater percentage error for samples 4 and 5 than in first three samples. In other words, the model has better ability to predict longitudinal changes for samples with high linear density. Fabrics with high density have higher utilization in garment industry; therefore this model is suitable for predicting length changes of knitted clothes that become wet through sweating or external sources.

## 6 CONCLUSION

In this study, shrinkage behavior of plain knitted fabrics was investigated. Initially by considering several hypotheses, a nonlinear model consisting of a concentrated mass, linear spring and damper was presented. Because the fabric was wet, hence the mass was changing over the time. Consequently, Three-order Straight Forward Expansion method was used to solve the related non-linear equations. In addition, dynamic behavior of fabric was simulated after drying.

After determining the motion equation, genetic algorithm was used in order to minimize the influence of linearity of mass changes towards time. Model and optimized results (by using Genetic Algorithm) were compared with experimental results of five samples with different courses density. The basic parameters of model were determined by curve hysteresis. The results showed, there is a better match between experimental and theoretical results for higher densities (Error of model is: 11.3 percent and error of optimized model is: 5.7 percent). By decreasing density, errors increase (error of model is: 18 percent and error of optimized model is: 6.15 percent); Therefore, it can be said that the proposed model is appropriate for high density fabrics which are more popular in clothes industry.

---

## REFERENCES

---

- [1] Won, S.M., "A study of the shrinkage of plain knitted cotton fabric, based on the structural changes of the loop geometry due to yarn swelling and deswelling," *Textile Research Journal*, Vol. 37, No. 5, 1967, pp. 417-431.
- [2] Knapton, J. J. F., and Yuk, F. K. C., "The geometry, dimensional properties, and stabilization of the cotton punto-di-roma structure," *Journal Textile Institute*, Vol. 67, No. 3, pp. 94-100.
- [3] Amirbayat, J., Alagha, M. J., and Porat, I., "Factors affected by machine settings and fabric properties in knitwear production, part I: seam shrinkage and thread consumption," *Journal Textile Institute*, Vol. 86, No. 1, 1995, pp. 110-118.
- [4] Higgins, L, Anand, S. C, Hall, M. E and Holmes, D. A., "Effect of tumble-drying on selected properties of knitted and woven cotton fabrics: part II: effect of moisture content, temperature setting, and time in dryer on cotton fabrics," *Journal Textile Institute*, Vol. 94, No. 1, 2003, pp. 129-139.
- [5] Onal, L., and Candan, c., "Contribution of fabric characteristics and laundering to shrinkage of weft knitted fabrics," *Textile Research Journal*, Vol. 73, No. 3, 2003, pp. 187-191.
- [6] Chen, Q. H., Au, K. F., Yuen, C.W.M., and Yeung, K.W., "An analysis of the felting shrinkage of plain knitted Wool fabrics," *Textile Research Journal*, Vol. 74, No. 5, 2004, pp. 399-404.
- [7] Ucar, N., and Karakas, H.C., "Effect of lyocell blend yarn and pile type on the properties of pile loop knit fabrics," *Textile Research Journal*, Vol. 75, No. 4, 2005, pp. 352-356.
- [8] Lo, W.S., Lo, T.Y., and Cho, K.F., "The effect of resin finish on the dimensional stability of cotton knitted fabric," *Journal Textile Institute*, Vol. 100, No. 6, 2009, pp. 530-538.
- [9] Souza, A. A., Cherem, L. F. C., Selene, M. A., and Souza, G.U., "Prediction of dimensional changes in circular knitted cotton fabrics," *Textile Research Journal*, Vol. 80, No. 3, 2009, pp. 236-252.
- [10] Rebecca, R., Amber, V., Niven, B.E., and Wilson, C.A., "Effects of Laundering and Water Temperature on the Properties of Silk and Silk-blend Knitted Fabrics," *Textile Research Journal*, Vol. 80, No. 17, 2010, pp. 1557-1568.
- [11] Postle, R., and Munden, D. L., "Analysis of the dry-relaxed knitted-loop configuration: part I: two-dimensional analysis," *Journal Textile Institute*, Vol. 58, No. 8, 1967, pp. 329-351.
- [12] Mozafary, V., Payvandy, P., Jalili, M.M., "Non-linear behavior simulation of the drying of weft knitted fabric by using mass- spring-damper model and straight forward expansion," *Modares Mechanical Engineering*, Vol. 14, No. 1, 2014, pp. 1-8.
- [13] Nayfeh, T and Mook, D., "Nonlinear oscillations. New York: Wiley Classics Library Edition Published," 1995, pp. 51-54.
- [14] Li, Y., and Dai, X.Q., "Biomechanical engineering of textiles and clothing," North America: CRC Press LLC, Woodhead Publishing Limited, 2006, pp. 115-120.
- [15] BS 5441, "Methods of test for knitted fabrics," 1988.
- [16] D2594-99a, "Standard Test Method for Stretch Properties of Knitted Fabrics Having Low Power," 1999.
- [17] Lobo, F. G., and Goldberg, D. E., "The parameter less genetic algorithm in practice," *Informatics and Computer Science*, Vol. 167. No. 1, 2004, pp. 217-232.
- [18] Scrucca, L., "GA: A Package for genetic algorithms in R. J," *Statistical Software*, Vol. 53, No. 4, 2013, pp. 1-37.